NEW ZEALAND MARINE DEPARTMENT

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A NEW ZEALAND TROUT STREAM

Some Facts and Figures

(Being a shortened and simplified account of the studies described in detail in Fisheries Bulletin No. 10)

By

K. RADWAY ALLEN

Senior Research Officer (Freshwater), Marine Department

WELLINGTON, NEW ZEALAND

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Chapter 1 : THE PROBLEM

THIS book is an attempt to set out in simple language, for the benefit of the angler, the results of a scientific experiment which was aimed at the question:

Where do the trout come from and where do they go to ?

This question puts in a few words almost the whole aim of freshwater fisheries research in New Zealand. The answers to it will do much to show how our trout streams should be managed so as to give each angler the best possible catch.

THE EGGS

Most of us know that the ancestors of the New Zealand trout came from overseas. The brown trout were brought from Europe via Tasmania in the 1860's and 1870's. The rainbow trout were brought from North America in 1883 and later years. Today almost all our trout stocks are well established, and the question of where they came from originally has only historical interest. The real question now is, Where have the trout which we catch or see swimming in our streams come from? Obviously they all started as eggs, but we need to know the origin of those eggs and where they hatched. Were they produced in the stream we are considering, or in some other water, so that the trout have had to migrate to their present home; or were they reared in a hatchery? It is of special practical importance to know how much the hatchery-produced fish have added to the stock in the river and to the anglers' catch. This will tell us whether the return which the hatchery yields is great enough to justify the expense of running it.

FOOD IS THE MAIN SOURCE

After the young trout hatches from the egg it lies quietly in the gravel for a time while it uses up the rest of the food which was stored in the yolk of the egg. When this is almost gone it wriggles up to the surface of the gravel and begins to feed, mostly on small insects. It is at about this stage that most of the trout produced in the hatcheries are liberated. The trout is now about 1 in. long, and it takes about 4,000 of them to weigh 1 lb. By the time the angler catches it the trout is at least 9 in. long and weighs at least a quarter

of a pound. Thus, although every trout we catch started its individual existence as an egg, only a very minute fraction of its weight when caught has been contributed by that egg. The rest of the weight has obviously come from its food. To answer fully the question " Where do the trout come from? " we therefore need to understand something of the way in which the trout obtains its food and of the process by which the food becomes changed into trout flesh and bone.

Most anglers know that trout feed mainly on small insects and similar creatures and sometimes, when large, upon small fish. The rainbow trout, but not the brown trout, also often eats water weeds. Some of the insects which the trout eat live in the water; others come from the neighbouring land. The amount of food which a stock of trout can get obviously depends largely on the amount it can draw from these sources. It also depends on whether the trout eats freely all the various kinds of creatures which live in, or fall into, the stream, or whether for any reason it feeds only, or mainly, on a few particular kinds.

HOW MUCH FOOD?

The food which a trout, or any other animal, eats is not converted directly into the substance of its body on a pound-for-pound basis. Part of it is needed to maintain life and to provide the energy which the fish uses up in swimming against the current to maintain its position, or in searching for food. These needs have the first call on the food which the trout eats, and it is only the amount which is left after they have been met which can be used for growth. The material of which a trout is made consists of the same chemical elements as those in an insect or any other food animal, but they are differently arranged so as to form rather different substances. Both consist largely of such things as proteins and fats, but the particular kinds of protein, and kinds of fat, are different in a trout and in an insect. Thus even the food which remains available for growth after the amount necessary to maintain life has been taken cannot be directly absorbed into the trout's body. It has to undergo a rather complicated conversion to make it fit to become part of the trout. This is not a very efficient process, and the amount of trout protein, fat, bone, &c., which is finally formed is less than the amount of material from which it was made. The rest goes to waste. Therefore, to answer the question " Where do the trout come from? " we have to find out not only what kind of food they have eaten, and where it came from, but also what use they have made of that food, and what proportion they have been able to absorb into their own bodies.

Nearly all the substance of the trout we catch has come originally from their food, but even when we have found answers to the problems discussed

Plate I. The lowest region of the Horokiwi, Zone I, has steep and stable banks and there are plenty of deep pools.

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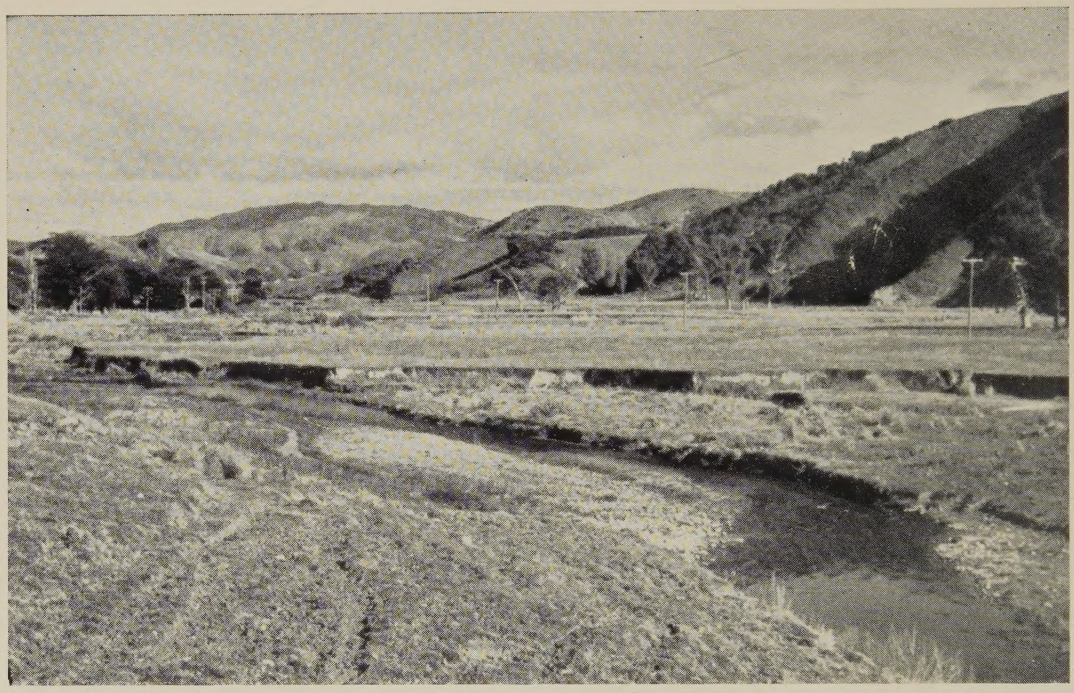

Plate II. Farther up the Main Water, in Zone II, the banks become lower and less stable, and there is much less deep water.

in the preceding paragraphs we still cannot be sure whether the quantity of trout in any particular water is being restricted by the amount of food that is available. It is a commonplace of farming practice that any particular piece of land will only support a limited amount of stock. If it is good land it will carry three or more sheep to the acre; if it is poor hill country it will carry one sheep to 10 acres, or even less. In the same way the carrying capacity of any particular stream or lake is limited, and it will not support more than a certain quantity of trout. The farmer can, as a rule, put into any paddock the quantity of stock that is appropriate to it, and so make sure that its carrying capacity is fully used. It is not usually possible to achieve similar control of the fish stock in a stream. Natural enemies or limited spawning areas may sometimes prevent the stock from increasing to the limit of the carrying capacity of the water.

To find out whether the carrying capacity is being fully used we can compare the amount of food the existing trout stock needs with the quantity the stream will provide. To do this we must measure these quantities of each of the main types of food (*e.g.*, the insects, &c., living on the stream bed—" bottom fauna "; and those of land origin which fall into the stream—" surface food," &c.) This is a fairly simple matter for the surface food; all we need to do is to discover how much drifts down the stream every day. Most of these animals have already reached the end of their lives, and the fact that the trout eat them does not affect the future supply. The bottom fauna presents us with a rather more complicated problem. It is quite easy to find out, by suitable methods, roughly how much bottom fauna there is in the stream on any day. The real difficulty lies in relating this to the amount which the trout stock can eat each day without imperilling future supplies. Rather indirect methods have to be used to find out how the surplus over the essential breeding stock of bottom fauna is related to the actual amount present in the stream.

WHERE DO THEY GO?

We can turn now to the second half of our question, " Where do the trout go to? " Whether they come from the hatchery or are produced by natural spawning, the number of trout fry entering our streams is vastly greater than the number of fish that anglers take out. At the present time the total angling catch for the whole of New Zealand is probably rather less than one million fish per season. In the past the hatcheries of New Zealand have produced as many as 20 million fry in a season, or twenty times the present-day angling catch. In addition, there is abundant evidence that the quantity of fry produced in the hatcheries is very small compared with the number produced naturally. Obviously, therefore, only a very small proportion of the fry which appear in our rivers each spring ever reach the angler's bag. The great

It was obvious from the first that the investigation would have to be very carefully planned if the results hoped for were to be achieved. A wide variety of observations would have to be made almost simultaneously, and the resources available were very limited. Only one scientist was available for the work, and the only possible additional help consisted of a single helper for the field work.

To get answers to our questions the study must include:

The stream in which the trout live.
The trout stock itself.
The food supply available to the trout.
The natural enemies of the trout.
The anglers and their catch.

THE STREAM

Information about the stream is needed for two main purposes. It is directly useful, since conditions in the stream may effect the growth or abundance of either the trout themselves or the insects and other animals upon which they feed. Indirectly, knowledge of the stream is necessary for the measurement of the abundance of both trout and bottom fauna. It would obviously be impossible to count all the trout or all the insects in the whole stream. Such counts must in practice be made by finding out how many fish or insects there are in a convenient area, and then multiplying the result by the number of times the sample area is contained in the whole stream. Very approximate results could be obtained in this way by treating the stream as a whole, but the differences in trout or insect populations between, for example, the upper and lower parts of a stream, or the pools and the rapids, are such that much more accurate figures can be got by estimating separately the population of each distinct part of the stream and then combining the results.

For both direct and indirect reasons we therefore need to know what kind of conditions as to depth, current, nature of bed, &c., occur in the stream selected for study, and to measure at least approximately the area occupied by each of the principal types in each part of the stream.

To get this information the stream was divided into a succession of short sections. Each section was in itself fairly uniform in current, depth, nature of bed, &c. The sections were classified according to their character into five main types—pools, flats, runs, stickles (rapids), and cascades. The survey party measured the length of each section and recorded at a number of points the width, depth, current, and the nature of the bed. From these measurements the area of each section was worked out, and from these results the total area of each type of water in any part of the stream was calculated.

Plate III. Part of the lowest reach of the Road Branch, Zone III, runs through a small area of native bush. Here much of the water is overgrown by trees, but there are small grassy glades.

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Plate IV. Farther upstream, in Zone IV, the valley walls become very steep and rocky and the stream is flowing through a narrow gorge. Much of the stream is overgrown with gorse in this zone.

THE TROUT STOCK

Much more information was needed about the trout stock since the aim of the whole work was to be the understanding of the factors which controlled it. First of all we must know whether the fish we see and catch in the selected stream were hatched in that stream and had lived there all their lives. If this is not so it adds greatly to the complications of the problems, since it then becomes necessary to make allowances for the food consumed, and the growth made, in the other waters. In the same way it is necessary to know whether the trout are moving freely throughout the whole stream or whether they tend to stay in one place so that there are, in effect, a succession of local populations spaced along the stream.

With the nature of the fish population thus established the further information required about the trout is concerned mainly with three features. These are the numbers surviving to various ages, the rate of growth, and the kind and quantity of food eaten. Owing to the limitations of staff and other facilities it was necessary to plan the work so as to collect information about all these points at the same time. The method used was to select a series of sampling areas along the stream, each of which was to be typical of the part of the stream in which it was situated. Each of these areas or "stations" was then netted at regular intervals. All fish caught were weighed and measured, and scale samples taken; some fish were killed for the examination of their stomach contents. All the fish not killed were released in the place where they were caught, and unless they were too small they were tagged before being released.

These observations yielded knowledge on most of the essential points previously discussed.

THE DISTRIBUTION of the population (*i.e.*, the extent to which it was restricted to the stream under study and the extent to which local populations existed along the stream) was shown by the movements of marked fish subsequently recaptured.

THE NUMBERS SURVIVING were given for each station by the number of fish of each year-class present at the time of each netting. Allowance had to be made for the fish not caught, since even the most efficient netting will not take all the fish in any piece of water. This allowance could be made fairly accurately on the basis of the proportion of the fish which were found to be marked in later netting. From the numbers of fish found to be in the netting station the total population in each part of the stream could be worked out fairly reliably. To enable the total population of each region of the stream to be worked out the whole stream was netted as thoroughly as possible on one occasion. The relation then found between the population of each routine netting station and the whole of the region in which it lay gave a reasonably accurate means of estimating the populations of the regions on other occasions when only the station was netted.

The same records would tell us how many eggs are produced each year to start the next generation. From the fish killed for closer examination we could find what proportion of the female fish were mature at any age, and how many eggs each produces. Since we would already know the number of female fish of each age in the population it is easy to work out the total egg production for the coming spawning season.

As an additional check on the egg production each year an attempt was made to count as completely as possible all the spawning redds formed in the stream. Excavation of some of these enabled the average number of eggs in them to be counted and so provided a second means of calculating the total egg production. The excavations also provided an opportunity of studying the amount of mortality which occurred among the eggs while in the redds, and continuous observations on the redds revealed the extent to which they were damaged by floods. The recording of the redds also showed the extent to which the different parts of the stream were used for spawning.

FOOD AND GROWTH

THE RATE OF GROWTH was shown by the size, at successive dates, of the fish of any one year-class. It was therefore easily obtained from the results of weighing and measuring all the fish caught, since their age could be reliably determined. When fish are small and growing fast their size alone is often a reliable indication of their age, once the rate of growth in the particular water is roughly known. When they are older and the sizes of different age-groups may overlap additional methods may become necessary, and it was for this purpose that scales were taken from all fish.

THE KIND OF FOOD which the trout ate was found from the examination of the stomach contents of the fish killed. For this purpose it was necessary to ensure that fish examined were taken at all seasons and at various times of the day and night, and also that fish of all ages were included. This examination also helped to show, from the quantities of food found in the stomachs, how much food the trout ate. To find this out it was also necessary to know how fast a trout digests its food.

The main problems directly affecting the trout which would be left unanswered after an investigation on these lines were those concerning the proportion of the trout coming from the hatchery, the quantity of food actually needed by the trout and the efficiency with which it was converted, the causes of death, and the yield to the angler.

The proportion coming from the hatchery can easily be found by comparing the official records of liberations with the estimates of total population already discussed.

The food requirements of individual trout and the efficiency of conversion have to be worked out from special experiments. In these fish are kept under carefully controlled conditions and fed with known quantities of food and their growth observed. Fortunately, sufficient experiments of this kind have already been done to give us a useful knowledge of the amount of food which trout need to grow at various rates. The food requirements of the entire stock could be worked out by combining the results of these experiments with the information already collected regarding the numbers and rate of growth of the trout.

MORTALITY AND ANGLING

The information about mortality rates which was obtained by finding the number of survivors to each age gave a basis for studying the causes of death. Further information could be got by examining the abundance and feeding habits of possible natural enemies of the trout, such as shags and eels. Such studies were therefore included as far as possible in the investigation. The netting done to catch trout also took eels fairly freely, and useful information about these important predators could be expected from this work at the cost of little extra time.

The basic facts about the angling catch could only be got from the anglers themselves. It was therefore necessary to devise a means of getting this information from the anglers. With the staff available it was obviously impossible to contact each angler every time he fished the stream. The best solution seemed to be to attempt to interview as many as possible of the anglers who fished the selected stream, and to persuade them to keep a simple diary recording their results. If all or most of the anglers concerned could be contacted, and were willing to co-operate, a reasonably complete record could be hoped for.

FOOD SUPPLY

The main sources of brown-trout food are known to be surface food, the bottom fauna, and small fish. Earlier work had shown that the bottom fauna was likely to be much the most important of these. Comparison between the amount of food eaten by the trout stock and the amount available to it therefore called mainly for an accurate measurement of the amount of bottom fauna in the stream. The density of the bottom fauna, which is the amount present in a given area of stream bed, is likely to vary both from place to place in the stream, and from time to time. The variation with time will be caused both by the natural life-cycles of the insects, &c., concerned, and by external effects such as floods, which may destroy part of the fauna.

The study of the bottom fauna could best be done in a somewhat similar way to that of the trout. Measurements were concentrated on the same representative areas, the stations; and at these places they were made at regular intervals. The small size of the animals of the bottom fauna and their habit of living among and under the stones of the stream bed made very laborious and detailed methods necessary for this study. It was no longer possible to try to cover a whole station in the way that was done for the trout. The only thing to do was to take a number of very small known areas in various types of water in each station and to try to collect the entire bottom fauna from each of these. The results showed the density of the bottom fauna in the various types of water in each part of the stream, and, when combined with the information about the area got from the survey, made it possible to measure approximately the entire bottom fauna of the stream, or of any part of it.

The most convenient area to use for this purpose was 1 square foot, and a special scoop had been devised for digging up this area of the bed without losing the little animals from among the stones. From these samples of stream bed the animals were removed by washing, sieving, and sorting. After removal in this way they were counted and weighed. As the different animals of the bottom fauna may be eaten by trout to different extents it was necessary for each kind to be counted and weighed separately, so that an independent measurement of its density and total population could be made.

Information about another useful, though minor, source of trout food, the small fish, was obtained incidentally during the netting done to study the trout. This enabled us, without doing any special work, to obtain at least a rough measurement of the abundance of small native fish and revealed any differences between the various parts of the stream.

It did not seem worth-while with the limited resources available to devote any time to the study of the surface food, since this was found to form only a small part of the food of the trout studied, and would have required special methods and additional time for its measurement.

SUMMARY

The main points of the programme were therefore:

A survey of the stream itself to show the area of each type of water and of bed in every part of the stream.

The regular netting of representative lengths of stream to give information on numbers of fish, their movements, growth, and feeding habits. These nettings were generally done at three-monthly intervals and were supplemented as necessary by collections at shorter intervals for the study of growth and food only.

The netting of as much of the stream as possible on one occasion to provide a basis for working out the total population from that of the sample areas.

The examination of the stream in the spawning season to record the number, distribution, and fate of the redds.

The examination of liberation records to show what proportion of the stock had its beginning in the hatchery.

The use of existing research results to work out the total food requirements from the data on numbers and rate of growth which were obtained from the netting programme.

Observations on natural enemies to collect information on causes of mortality.

The recording of anglers' catches by means of a voluntary diary scheme.

The measurement of the density, and so the population, of the bottom fauna by taking one-square-foot samples in each type of water in each station at regular intervals. These were done at two-monthly intervals as far as possible.

The study of the small native fish as a source of trout food. This was done incidentally during the regular netting for trout.

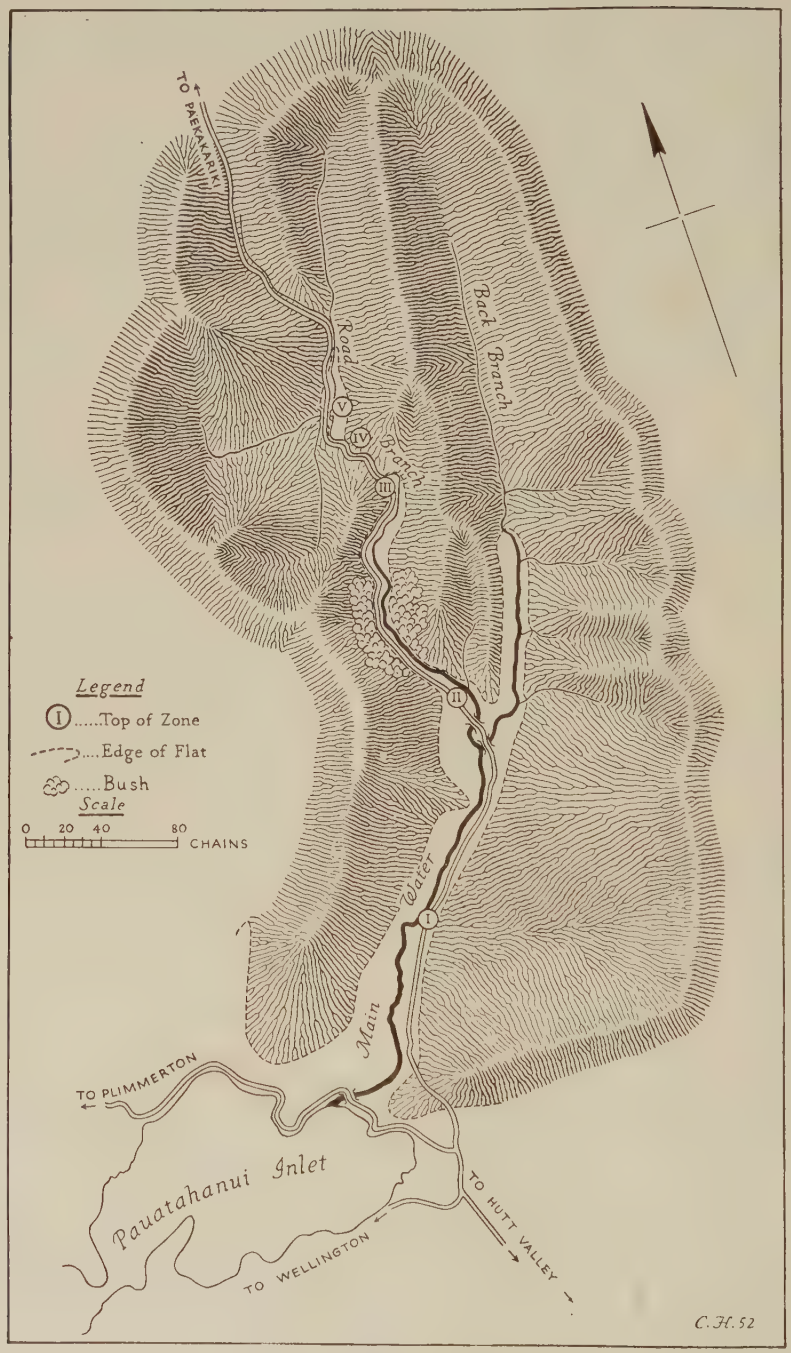


Fig. 1. Map showing the course of the Horokiwi and the zones into which it was divided.

Chapter 3: THE PLACE

REQUIREMENTS

When a plan of campaign had been drawn up, as described in the previous chapter, the next step was to select a suitable stream for the work. Obviously a research programme of the size planned could only be followed on one stream at a time. On the other hand, if the results were to have practical value, they must be capable of the widest possible application. It would be a waste of time and effort to undertake such a long and detailed study if the results could only be given practical application on the stream where the work was done. The fact that the whole object of the scheme was to increase our understanding of the principles governing the yield obtained from trout waters would itself ensure to some extent that the results could be widely applied. It was also desirable that the stream chosen should be as typical as possible of at least one important class of trout waters. For fairly obvious reasons the following additional characteristics were also laid down as being essential for the selected stream:

1. Suitable size. In order to make the investigations as complete and thorough as possible the stream should be no larger than is necessary to provide an adequate quantity of trout. A total length of 7 to 10 miles seems to be indicated.

2. A minimum of tributaries and forks, since the less a stream branches the greater the proportion of the total length of waterway which is of sufficient size to carry a stock of trout.

3. It must be a separate stream entering the sea independently, since in a tributary of a larger stream there would be an interchange of fish between the main stream and the tributary which would make the proposed work impossible.

4. There must be a full stock of trout.

5. As much of the stream as possible should be of a type of water reasonably easy to net.

6. There should be no dangerous pollution in any part of the stream.

7. The stream should be within easy driving distance of Wellington, say, 50 miles.

8. As much of the course as possible should be reasonably close to a road.

THE SELECTED STREAM

A careful examination was made of all possible streams within the prescribed area, and finally the Horokiwi Stream was selected as the most suitable. Field work was begun there early in 1939 and was continued until October 1941, when the war forced its abandonment. The angling records have been carried on continuously since 1939 and have shown the effect in later years of some of the events which took place between 1939 and 1941.

The Horokiwi has been well known to Wellington anglers for a number of years as one of the best of the smaller streams in the district, particularly in the early part of the season. In 1938 it was described in glowing terms in the Annual Report of the Wellington Acclimatization Society; this said, "a most remarkable stream is the Horokiwi . . . to the casual observer it appears to be only a weed-infested creek, but what a stream in the earlier part of the season. It has a reputation well known to anglers, and maintains it year after year; in fact, such streams are the salvation of many anglers when conditions are not right in our larger waters; they never let one down."

It was probably known more casually, and perhaps not by name, to an even greater number of anglers from outside Wellington. Prior to the opening of the coastal highway from Plimmerton to Paekakariki in 1940 the main road from Wellington to the north led up the Horokiwi Valley from the Pauatahanui inlet before dropping down the steep descent to Paekakariki. Thus, up to that time, any traveller by road from Wellington to the Manawatu or farther north must have passed along the Horokiwi Valley and seen the stream lying either close alongside the road or else, farther upstream, below him at the bottom of the gorge.

The Horokiwi, which is shown on the map in Fig. 1, closely satisfied the conditions laid down. Its total length is about 10 miles, and, until it breaks up abruptly into a number of headwater streamlets, it has only one fork of any significance. This fork lies about $3\frac{1}{4}$ miles from the sea, and there the stream divides into two roughly equal branches. The western branch runs close to the road throughout its length and was therefore known as the Road Branch, the eastern branch which runs back into the hills was called the Back Branch—the combined stream between the forks and the sea was referred to as the Main Water.

The original plan was to include the whole of the Horokiwi system in the study, but lack of time soon made it necessary to limit the work to the Main Water and the Road Branch below the point where it began to divide. The total length of stream studied was therefore about $7\frac{1}{2}$ miles. The work soon showed that the Horokiwi trout were so stationary in their habits that the exclusion of the Back Branch from the observations would not seriously complicate the results.

The small streamlets which unite to form the Road Branch rise close to the sea along the crest of the ridge overlooking Paekakariki and the Horowhenua Plain. These hills, which are rather irregular in formation, generally lie between 1,000 ft. and 1,400 ft. above sea-level. After the junction of these small streams the combined waters flow, as the Road Branch, through a narrow, rather winding valley towards the confluence with the Back Branch. In places the narrow floor and steep walls of the valley give it a gorge-like appearance, but elsewhere there are small relatively open basins. Finally, the Road Branch runs, rather suddenly, out of the narrow valley and flows through extensive river flats, a quarter to half a mile wide, between widely separated hills. Shortly below the head of this wide valley the Back Branch enters from the east, and from its junction the Main Water flows along an almost straight course to the sea. The only break in the wide valley floor occurs shortly below the junction of the two branches, where a low rocky ridge runs across the valley and forms a short gorge section in the stream.

Although the whole of this part of New Zealand was originally covered in heavy bush, the Horokiwi Basin was largely cleared between about 1850 and 1880, and today the drainage area is almost entirely in grass. The river-flats are used mainly for dairy-farming and the hills carry sheep. In the lower valley the few trees present are in isolated lines and groups, and hardly any of the water is shaded by them. On the steep valley walls of the Road Branch, although the ridges and hill-tops are all in grass, there is a greater growth of trees and scrub. In the lowest part of the Road Branch valley there is a considerable area still in native bush. Farther up a great deal of the valley walls and floor had, at the time of this work, been neglected for many years and were densely covered in scrub, particularly gorse. As a result, except for a few cleared areas, the waters of the Road Branch, above the main valley, were largely overhung and shaded by trees and bushes.

SUBDIVISIONS OF THE STREAM

It was at once obvious that the part of the Horokiwi which was to be studied consisted of two very distinct regions. The lower region comprised the whole of the Main Water and a short part of the lower end of the Road Branch, and here the stream lay in the open and flowed through alluvial plains. In the upper region, comprising the rest of the Road Branch, the stream lay generally in a narrow steep-walled valley and was largely overhung with trees and scrub. These two main regions will be referred to in future as the *Lower Waters* and *Upper Waters* respectively.

As the study developed, it became apparent that each of these main regions could be subdivided into three parts, which differed from each other both in the nature of the stream and in their trout populations and food supplies.

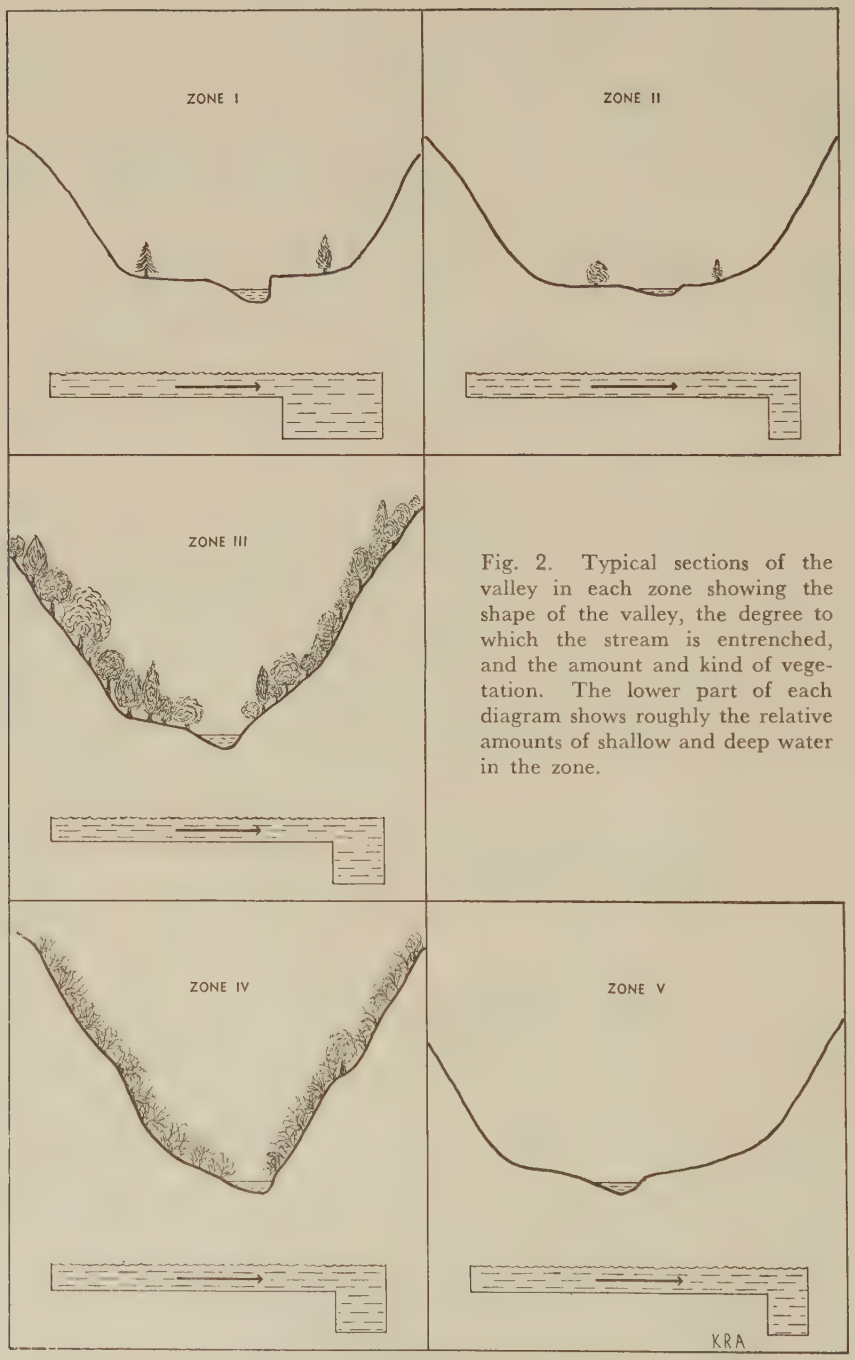


Fig. 2. Typical sections of the valley in each zone showing the shape of the valley, the degree to which the stream is entrenched, and the amount and kind of vegetation. The lower part of each diagram shows roughly the relative amounts of shallow and deep water in the zone.

These subdivisions were called zones and were numbered in their order upstream:

ZONE I occupied the lowest two miles of the Main Water. The stream here was stable with high banks, and plentiful pools up to 6 ft. deep.

ZONE II formed the rest of the Lower Waters, the part on the Main Water ($1\frac{1}{4}$ miles) being called Zone IIM, and that on the Road Branch ($1\frac{1}{4}$ miles) Zone IIR. This zone was relatively unstable, and the very few pools were nearly all shallow.

ZONE III, the lowest of the Upper Water zones, was about $1\frac{3}{4}$ miles long. The stream was fairly stable with numerous rocky pools and lay in a U-shaped valley. Unlike the lower zones, the stream here was largely overhung with bush and scrub.

ZONE IV, in which the stream was similar to that in Zone III, but rather steeper and more rocky. The valley here formed a steep-sided gorge, often with sheer rock sides falling straight into the stream. The banks were overgrown with gorse. This zone was 1 mile long.

ZONE V (one-third of a mile), lay in a small open basin at the head of the stream. The banks were open, and the gradient gentle. Conditions generally resembled those in the lower waters, with a degree of stability intermediate between Zones I and II.

The main characteristics of the zones are summarized in Fig. 2.

In addition to these changes in the stream and the valley through which it flowed there were also noticeable differences in the nature of the stream-bed in the various zones. Apart from a few patches of rock and clay it consisted everywhere of a mixture of sand, shingle, and stones of various sizes. In any one part of the stream there were local variations due to the shape of the channel and the force of the current, the finer deposits being generally found in the quieter water. Apart from this, the average size and shape of the stones varied from zone to zone. As in most rivers, there was a general tendency for the stones to be smaller and rounder farther downstream. This tendency is due to the breaking and grinding which goes on as the stones are carried downstream, generally in floods. In the Horokiwi, at present, the gorge of Zone IV is probably the main natural source of stones for the stream-bed, and the quantity coming from this area has been increased by the stone released into the stream in the cutting of the road along one side of the gorge. As a result, the average size of the largest stones usual in the stream-bed decreased

steadily from nearly 10 in. in Zone IV to less than 4 in. in Zone I. There was a similar decrease in the angularity of the stones, although this is not so easily measured. The exception to this general tendency was found at the head of the stream in the basin of Zone V. This lies above the gorge and the stones which form the bed here have been brought down from the smaller gullies of the tributaries and from the neighbouring hillside. They have therefore been subjected to a good deal more breaking and grinding than in the zones immediately below. As a result, the stream-bed of this zone is much more like that of the Main Water zones; the stones have an average size of nearly 6 in. and are well-rounded.

Chapter 4: THE TROUT

LIBERATIONS

Trout were first liberated in the Wellington Province in 1874, but it was not until 1883 or 1884 that the first liberations were made in the Horokiwi. In one of these two years a single liberation of 400 fry was made. From contemporary reports it is clear that, despite the small size of this first liberation, the trout thrived and multiplied very rapidly in the Horokiwi. In 1885 the first report of the Wellington Acclimatization Society, referring to the Horokiwi and the other streams entering the Porirua Harbour, states, " Well-grown fish are reported as having been frequently seen in all these streams, and the settlers have shown an intelligent interest in their preservation." Two years later, in 1887, the report says that already the trout are " very numerous " in the Horokiwi.

After the original liberation of 400 fry, which led to the establishment of the early " very numerous " stock, no further liberations were made in the Horokiwi until 1907, when 5,000 fry were released there. There was then another gap until 1918. In this and the following year small liberations were made. Regular liberations did not begin until 1923. They gradually increased in size for a time, but during the last twenty years they have been fairly steady at between 10,000 and 20,000 fry a year. During this period between 1 per cent and 2 per cent of the total number of fry liberated in the Wellington district have in most years gone into the Horokiwi. In contrast with this figure it is interesting to note that the Horokiwi only supports about 0·3 per cent of the angling in the Wellington district (*i.e.*, only about one-fifth of the relative amount of the liberations). The proportionally large size of the liberations is probably due to a belief that a small stream near two large towns needs to be very freely stocked if fishing is to be maintained. In a later part of this bulletin the truth of this belief will be examined.

It is thus evident that in the Horokiwi a trout stock became established very quickly after the first liberation, and there is no indication of any significant change in the size or number of fish since then. Few records are available before about 1925, but from this date until 1939 statements in the Annual Reports of the Wellington Acclimatization Society, and a few recorded anglers' catches, all suggest that the condition of the stock remained unchanged. From 1939 to the present day very full records are available, and these show that, while there have been minor variations from year to year, there have been no

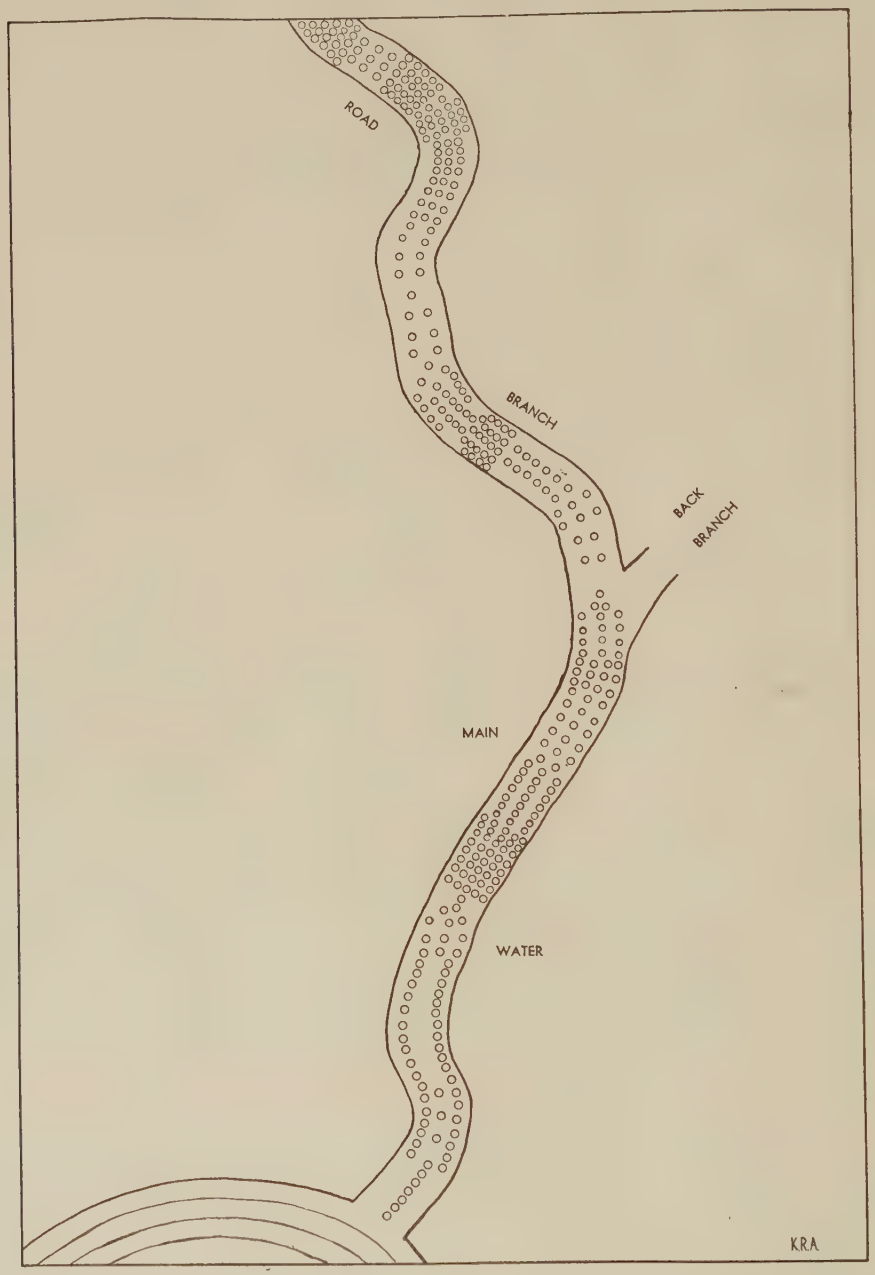


Fig. 3. Trout spawn in all parts of the Horokiwi and not only in the upper reaches. Each circle in the diagram shows roughly the position of a redd in the 1940 spawning season.

long-term alterations in size or abundance of fish. It seems safe to say, therefore, that the observations described in this bulletin were made on a well-established trout stock in a stable condition.

The methods used for the study of the trout have been outlined in a previous chapter, and the main results will therefore be discussed without further reference to the way in which they were obtained.

SPAWNING

Trout were found to spawn freely in all parts of the Horokiwi, and there was no definite spawning migration. In several instances marked trout were found spawning within a few yards of the place where they had been tagged some months earlier. This wide-spread spawning is well illustrated by Fig. 3, which shows roughly the position of every redd found in 1940, a year in which particularly complete records were obtained. In both 1940 and 1941 about 900,000 eggs were produced by the Horokiwi trout.

Only some of these eggs would ultimately hatch and produce fry. The failure of the others might be due to any one of a number of causes. Some eggs are never shed by the hen fish; some fail to lodge successfully in the redd; some die of suffocation or other causes during development; some are dislodged by later spawners; and some redds are destroyed by floods with loss of the eggs. Studies made on the Horokiwi and elsewhere enable the extent of the losses due to these causes to be known reasonably accurately. The unshed eggs form less than one-half per cent of the total number produced. The eggs failing to lodge are about 2 per cent. These two figures are unlikely to vary greatly for different trout stocks, but the losses due to the other three causes may vary greatly from water to water, and those due to floods also from season to season. Losses due to death during development in the redds seem to be higher in the Horokiwi than in many other streams, and individual redds examined showed losses between 23 per cent and 92 per cent. A total loss of 33 per cent, or one-third, is probably about the average. In the Horokiwi spawning is widespread, and disturbance of redds by later spawners is consequently less frequent than in water where there is little good spawning gravel, but it does happen occasionally, and losses up to about 10 per cent may arise in this way. It seems, therefore, that, before losses due to floods are taken into account, the natural production of fry in the Horokiwi in the years studied would be about 500,000. In 1940 no floods occurred, and as a result this number of fry was probably produced. In 1941, on the other hand, floods were quite abnormally severe, and it seems that about 80 per cent of the redds may have been destroyed in this way. This would give a fry production for that year of about 100,000.

These figures, which represent about the two extremes which would normally occur, may be compared with the number of fry liberated in the Horokiwi.

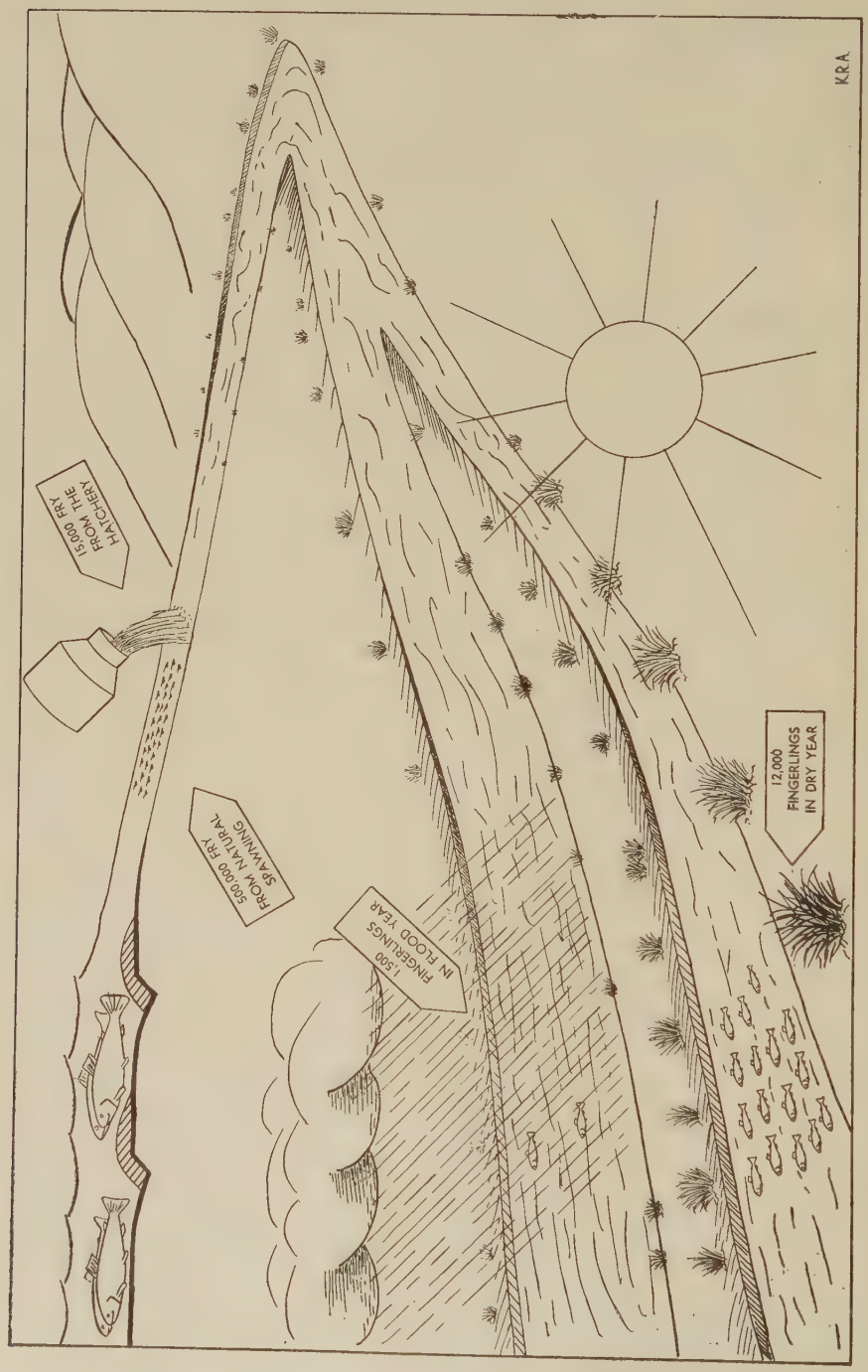

150 FRY FROM THE HATCHERY
500,000 FRY FROM NATURAL SPAWNING
1,500 FINGERLINGS IN FLOOD YEAR
12,000 FINGERLINGS IN DRY YEAR
K.R.A.

Fig. 4. The number of fry produced naturally in the Horokiwi is very much greater than that added by liberations. In the top half of the picture each fry represents about 15,000 added to the stock either by natural spawning or by liberations. The number which survive to fingerling size depends largely on whether or not there is serious flooding, as the bottom half of the picture shows.

This averages about 15,000. *We see, therefore, that even in a year of bad flood the normal liberation would only increase the number of fish in the Horokiwi by about one-seventh, while in a good spawning year the increase due to the liberations would be less than one in thirty.* Thus, even in a relatively heavily stocked stream such as this, only a very small proportion of the trout come from the hatchery liberations, even in those years when the redds are severely damaged by floods.

SURVIVAL

The numbers of fish surviving in the Horokiwi from a successful spawning such as that of 1940, when about 500,000 fry resulted from 900,000 eggs, are estimated to be about:

FIRST YEAR:	January	12,000	THIRD YEAR:	January	800
	May	7,500		May	550
	July	4,500		July	450
	October	3,700		October	300
SECOND YEAR:	January	3,000	FOURTH YEAR:	January	220
	May	2,000		May	150
	July	1,600		July	120
	October	1,200		October	85

FIFTH YEAR:	January	60
	May	40
	July	30
	October	15

The rate of mortality is obviously very much higher in the first few months of life than it is later. *In the first few months, from October to January, about 97½ per cent of the young trout die from one cause or another. After this time the mortality rate is fairly steady, and in each year about 80 per cent of the trout alive at the beginning of the year will die.* These results for the Horokiwi are very similar to those found for other trout stocks which have been studied in various parts of the world.

Although the average mortality rates were very similar in all parts of the Horokiwi, well-marked differences in the abundance of the various year-classes in the different zones were sometimes observed. These differences were particularly evident in the Road Branch zones. A very good example of this is provided by the 1937 year-class (the fish derived from the 1937 spawning); this group was practically absent from Zone III, but was unusually abundant in Zone IV. The causes of these local variations are uncertain, but they may be due to variations from year to year in the sites selected by the fish for spawning.

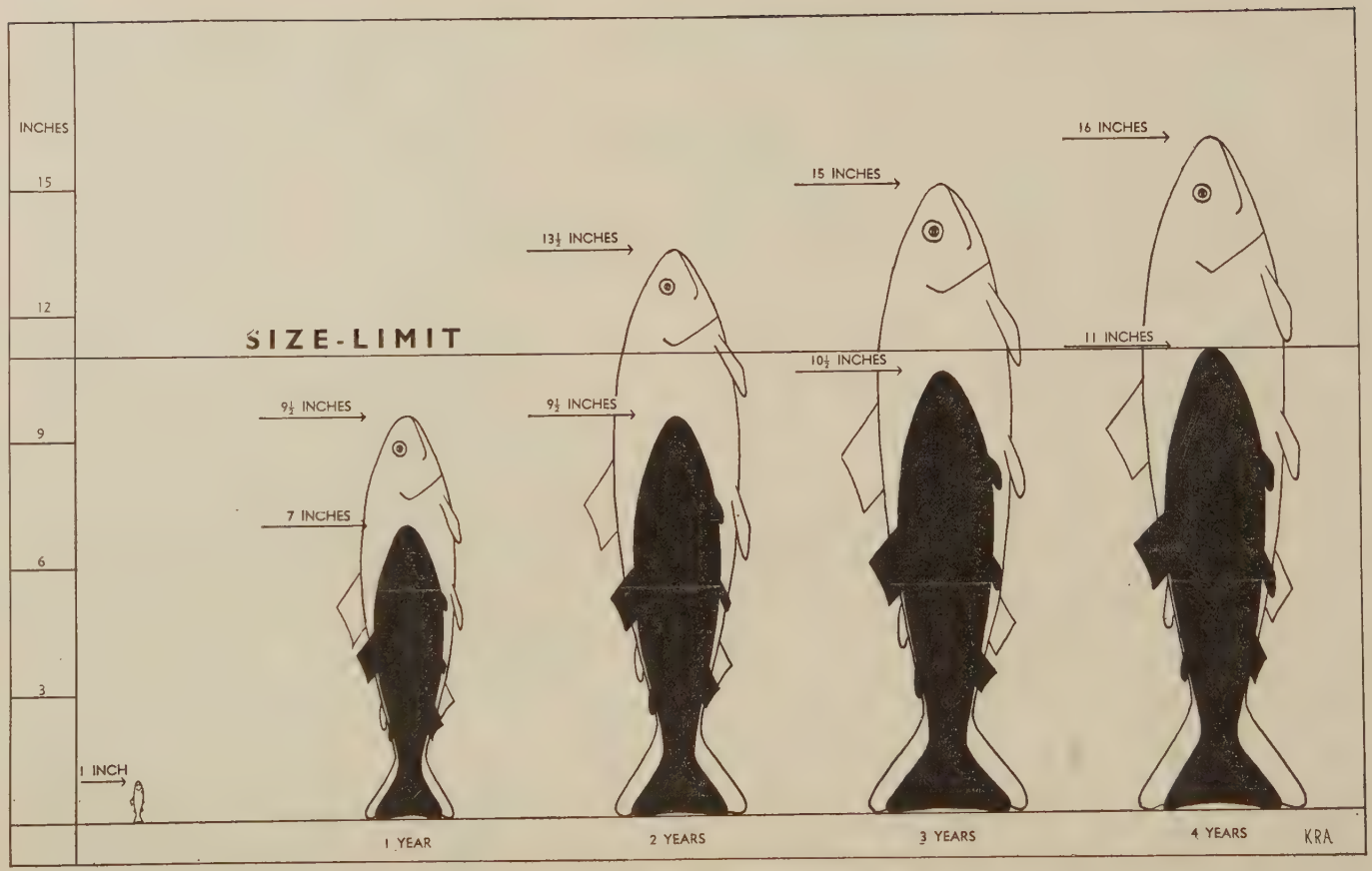


Fig. 5. The rate at which trout grow varies greatly in different parts of the Horokiwi. The white outlines show the size which they reach at the end of each year in Zone I, where growth is most rapid. The black outlines show growth in Zone IV, where it is slowest.

GROWTH

The rate at which the trout grew was found to vary greatly in the different zones of the Horokiwi, although it was usually fairly uniform within each zone. Growth was most rapid in Zone I. It became progressively slower upstream until it was at its slowest in Zone IV. In Zone V the growth rate again increased and was about the same as in Zone III. The two extremes were therefore found in Zones I and IV, and the average size of fish in these two areas at the end of each year of life is illustrated in Fig. 5. The white outline represents the fish of Zone I and the black outline that of Zone IV. The sizes of the fish can be compared on the diagram with the 11-inch size-limit. In Zone I the average fish becomes takeable early in its second year, but in Zone IV it is four years old before this size is reached. In Zone II trout become takeable at about the middle of the second year, and in Zones III and V at the beginning of the third year.

WEIGHT OF TROUT PRODUCED

From the numbers of fish surviving to any date, and the rates of growth, we can work out the total weight of trout which were present in the stream at any time, and also the amounts of additional trout flesh produced by growth within any period. From these results we can in turn find out how much has been lost from all causes during the period. To assist the reader to understand these relationships Fig. 6 shows in simple form approximately what happens, during the first three years of life, to 1,000 fry hatched in the middle part of the Horokiwi.

In this diagram the white fish are those which are still alive at the date in question, while the black fish are those which have died. The brackets joined by arrows between successive dates indicate the fish which have died during that period. These deaths obviously took place at various times during the period. Therefore, as the diagram shows, some fish die when little or no bigger than they were at the beginning of the period, but others survive until they reach larger sizes, so that the largest of them were, at the time of their deaths, about the same size as the survivors at the end of the period. In October the original fry each weighed about one two-hundred-and-fiftieth part of an ounce, so that 1,000 weighed a quarter of a pound. This is therefore the original total weight of the group of fish we are studying. By the following May only 15 survivors remain from the original 1,000, but these have grown until they weight rather less than 2 oz. each, so that, although the number of fish is so much less, the weight of the stock is actually very much greater than it was originally. Although a large proportion of the 985 fish which died during the period died when they were little larger than newly-hatched fry, others must have survived and grown until they were nearly 2 oz. in weight.

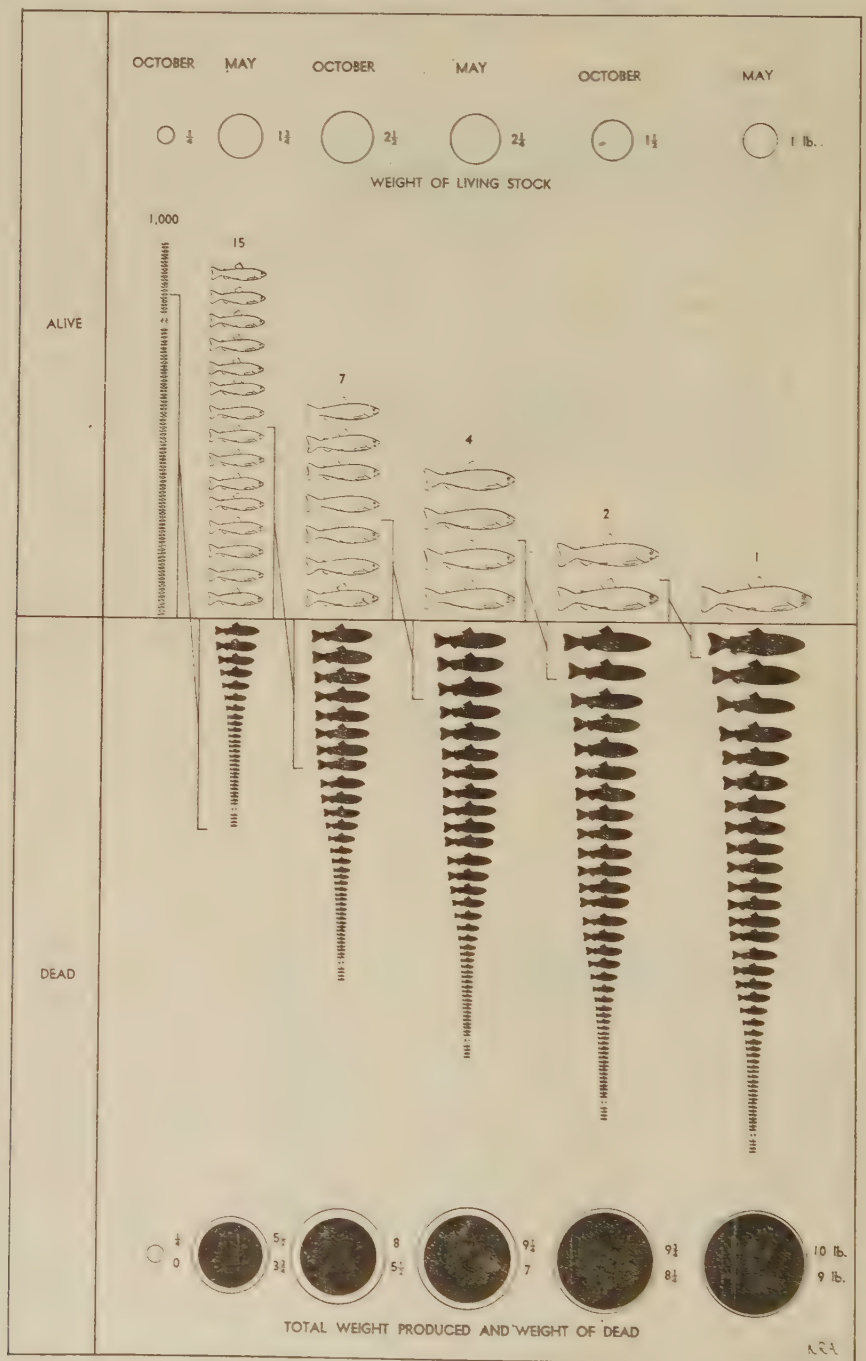


Fig. 6. The number of fish still surviving from a thousand fry, shown in white, decreases as they grow older and their individual weight increases. Their total weight, represented by the top white circles, increases at first and then decreases. The number of dead fish, shown in black, is increasing all the time, as is their total weight—the lower back circles. The total weight produced by the growth of the original 1,000 fry up to any date, is the sum of the dead and the living, and is shown by the black circles plus the white outer rings.

The amount of trout flesh which has been produced by growth during the period includes not only the increased weight of the fish which still survive, but also the increase in the weight up to the time of death of all the fish which died during the period. The fish which still survive have increased their combined weight by about $1\frac{3}{4}$ lb. The fish which died had added about $3\frac{1}{2}$ lb. to their original weight of $\frac{1}{4}$ lb. Thus in the first five months of life the growth of 1,000 fish we are following has led to the production of $5\frac{1}{4}$ lb. of trout flesh—or $5\frac{1}{2}$ lb. if the weight of the original fry is included. Of this amount only $1\frac{3}{4}$ lb., or about one-third, is still surviving in the stock even at the end of this short period.

During the next five months, up to October, 8 more of the survivors die, leaving only 7 of the original 1,000 to complete their first year. These have now grown until they weigh about 6 oz. each, so that the weight of the surviving stock still shows a slight increase and is now rather more than $2\frac{1}{2}$ lb. The eight fish which died during the period had also grown by variable amounts, but at the time of death they probably averaged about 4 oz., so that their total weight was also about 2 lb. Therefore, up to the end of the first year the total quantity of trout flesh produced by our 1,000 fish was:

Weight of survivors ($2\frac{1}{2}$ lb.)	+	Weight of those dying before May ($3\frac{1}{2}$ lb.)	+	Weight of those dying between May and October (2 lb.)	=	8 lb.

The proportion of the total quantity of trout produced which is still available in the surviving stock is again nearly one-third and is unchanged since the previous May.

At the end of the next period only four out of the seven fish survive, but these have grown to about 9 oz. each, giving a total weight of stock of about $2\frac{1}{4}$ lb. The three which died weighed about $1\frac{1}{2}$ lb., so that the total production has now reached $9\frac{1}{4}$ lb. The proportion of this represented by the surviving stock has dropped to about one-quarter.

By the following October, which completes the second year, only 2 of our original 1,000 fish remain. These have grown to about 12 oz. in weight, so that the stock weighs about $1\frac{1}{2}$ lb. When the growth made by the fish which died during the period is included, the total amount of trout flesh produced by this date is found to be about $9\frac{3}{4}$ lb. The stock is therefore now less than one-sixth of the total amount produced.

The final period included in the diagram takes us up to May of the third year. By this time only one survivor remains, and its weight, about 15 oz., forms the total weight of the stock. The amount produced has only increased slightly and is now about 10 lb. Only about one-tenth of the amount produced now remains as the stock.

After this time less than one survivor remains from the initial 1,000 fry, and our diagram cannot conveniently be continued. As we have seen, the

actual stock of the Horokiwi starts with several hundred thousand fry each year so that quite a number do actually reach much greater ages. In October 1940, for instance, the Horokiwi stock was estimated to include 295 three-year-olds, 40 four-year-olds, 32 five-year-olds, and 32 six-year-olds. After May of the third year there are no further changes in the tendencies which have already appeared, and as the year-class grows older the weight of the surviving stock continues to diminish, while the total amount produced increases more and more slowly, and finally becomes almost stationary after the fourth year.

PRODUCTION AND STOCK

In the different zones the variations in the character of the trout, and particularly in their growth-rate, cause corresponding changes in the amount produced and the weight of the surviving stock at any given time. In Zone IV, for example, where the growth-rate is much slower, the weight of the same number of survivors will, at any age, be much less than in Zone I at the same time. In the same way the amount of trout flesh produced by the growth in a given period of the same number of fish will also be much less in Zone IV than farther downstream. Despite these differences, the general trends, particularly in the relation between the amount produced and surviving stock, are essentially the same in all parts of the stream as they were found to be in the 1,000 fish from the middle reaches which we took as our example.

Everywhere the total weight of each year-class is very small at the time the fry hatch, but it increases rapidly as the young fish grow. As growth slows down, and death removes more and more of the original hatch, the total weight of the year-class increases more slowly. Finally, the removals by death equal, and then pass, the increase in weight due to growth. When this happens the total weight begins to decline, and goes on getting less and less until no survivors of the year-class remain. The total weight is, of course, greatest immediately before the decline begins. In the lower part of the stream this point is reached during the first half of the second year; in the upper part it is reached slightly later, generally just after the middle of this year.

The total amount of trout flesh which has been produced by the growth of the fish of any year-class goes on increasing all the time. At first, while the fish are abundant and growing rapidly, the increase is very rapid, but as the number of survivors falls off and the growth rate decreases with age, the quantity of new material being formed becomes less and less. By the end of the third year growth has become very slow so that production is virtually complete and the amount of additional material formed after this time is negligible.

As we have seen, the total weight of the living members of the year-class rises steadily from an initial low value to a maximum which is reached some

time in the second year, and then declines again. The total amount which has been produced during the life of the year-class rises throughout life, rapidly at first and then more and more slowly. The *proportion* of the amount produced which is still surviving at any one time does not follow quite such a simple course. At the moment of hatching the two quantities are identical, but as the young fry rapidly die off the proportion of the weight produced which is surviving quickly falls. After a few weeks, as the rate of mortality of the fry diminishes, the proportion of the weight produced which survives rises again, and then remains almost steady, at about one-third, until the weight of the stock begins to decline in the second year. From then on the weight of the stock is continually decreasing while the total weight produced increases. The proportion of the weight produced which survives in the stock correspondingly decreases continually from this time on.

In the lower waters we find that the total weight of trout flesh which has been produced by growth in a normal year-class is about 3,000 lb. by the beginning of the second year. Just over 800 lb. of this survives as the weight of the stock. From this time on the weight of the stock decreases, although the total weight produced continues to increase slowly and ultimately reaches a total of about 3,750 lb. In the upper waters the production by the beginning of the second year is about 900 lb., from which a stock weighing about 325 lb. survives. The ultimate total amount produced is about 1,250 lb.

It has been helpful to consider as a first step the changes in the production and stock of a single year-class during its life, but it is obvious that the population of the stream at any one time includes fish of a number of different year-classes. During any actual year the fish in the stream will include fry which grow to one-year-olds, one-year-olds which grow to two-year-olds, and so on. In a normal year the weight produced by the growth of the fish in their first year will be the same as that produced in the first year of the typical year-class. In the same way the amount produced by the second-year fish will be the same as that produced in the second year of the typical year-class, and so on. As a result the total weight produced by growth of all year-classes during a normal year will be equal to the total weight produced in the whole life of a single normal year-class. In the same way the total weight of trout present in the stream on any day will equal the weight of the typical year-class on that day in its first year, plus its weight on that day in the second year, and so on.

PRACTICAL CONSIDERATIONS

At first sight it may appear that an analysis of a trout stock on the lines of that just made is of purely theoretical interest and of little practical value. We shall see later that this is not so, and that realization of the difference between the actual quantity of trout present in the stock at any time, and the amount

which has been produced in obtaining that stock, does enable us to draw conclusions of great practical importance. Understanding of these quantities and study of the relationship between them shows what the factors are which control the yield that anglers can obtain from the stock, and also indicates what may be the effect of any measures designed to increase that yield.

Chapter 5: THE FOOD

HOW MUCH DO THE TROUT NEED?

Now that we have measured the quantities of trout that are produced and that survive in the Horokiwi we are in a position to work out how much food is needed for their maintenance and growth. To do this we must know how much food a trout needs every day to support life, and how much food is needed to form each pound of additional trout flesh produced as the fish grow. Other workers who have studied trout kept in laboratory tanks have given us this information with sufficient accuracy for our present purposes. From their work we know that:

A trout needs to eat 1·23 per cent of its own weight each day to support itself without growing.

For each pound added to its weight a trout must have had 4·2 lb. of food in addition to that which it needs for maintenance.

During the year ending May 1941, which may be taken as a fairly typical year, our studies have shown that there were, on the average, about 2,450 lb. of trout living in the Horokiwi (or rather over 1 ton). Each of the fish which went to make up this weight would need, for maintenance, about $1\frac{1}{4}$ per cent of its weight every day. From this we can work out that during the year the entire stock must have needed, *for maintenance only,* about 11,000 lb. of food, or about 5 tons.

During the same year the amount of trout flesh produced in the stream by the growth of all the trout present in the stream was just over 5,000 lb., or about $2\frac{1}{4}$ tons. For each pound of this additional flesh the trout must have eaten 4·2 lb. of food. The total quantity of food needed by the Horokiwi trout for *growth only,* therefore, amounted to about 21,000 lb. or $9\frac{1}{2}$ tons.

Thus we see that, in this fairly normal year, the trout in a small stream like the Horokiwi needed more than $14\frac{1}{2}$ tons of food. About one-third of this was used to support life and the other two-thirds for growth. In order to know how this amount compares with the quantity of food available to the trout we must, as explained in the first chapter, find out what the sources are from which the trout derive their food. General knowledge of trout tells us that the main sources are threefold:

The insect larvae and other small animals living among the stones and weeds of the stream bed (*bottom fauna*).

Insects and other animals of land origin which fall or are washed into the stream (*surface food*).

Small fish of various kinds.

The first problem is therefore to determine how much each of these main sources contributes to the food supply of the trout in the Horokiwi. As might be expected, *surface food* was found to be most often eaten by the trout during the summer. But even at this time it only made up about 5 per cent of the food which the trout ate, and during the rest of the year it was rarely more than about 2 per cent. *Small fish* were not found in the stomachs of trout until they were at least two years old. Even after this age the small fish found in the trout stomachs were very few in number, but they were so much larger than the insects that they formed quite a significant proportion (about 20 per cent) of the total weight of food eaten by the older trout. *From this we see that the bottom fauna is at all times much the most important source of food for trout in the Horokiwi.* It forms about 95 per cent of the weight of food eaten by trout in their first two years and about 75 per cent thereafter. When we realize that between 80 per cent and 90 per cent of the total food the trout eat is taken in their first two years (*i.e.*, before they have begun to eat small fish) we see that small fish only make a very small contribution to the total amount of food consumed. This may therefore, for practical purposes, be taken to consist almost entirely of bottom fauna.

HOW MUCH CAN THE STREAM PROVIDE?

In streams like the Horokiwi much the largest part of the animals on which the trout feed live on or among the stones of the open stream bed. A few, generally of rather different kinds, live in the cress and other weed banks which develop along the edge of the stream in some places. These are relatively very few, and the shingle bed can therefore be regarded for practical purposes as the only source of bottom fauna. The studies of the bottom fauna showed that there were generally between 300 and 1,000 animals living in each square foot of the shingle bed, and their total weight was generally about one-sixtieth of an ounce. Since the area of water in the stream was rather over 10 acres it follows that the average weight of bottom fauna present in the stream at any one time was about 450 lb., or one-fifth of a ton. *We find, therefore, that the quantity of bottom fauna which the trout eat in a year, 14 tons, is seventy times as great as the average amount of fauna present at one time.*

This result is startling enough in itself, but the contrast becomes even greater when we remember that not all the insect larvae, &c., in the fauna are equally freely eaten by the trout. Some of them are indeed very rarely taken, and consequently the relative amount required from the most freely eaten animals must be very much greater than the average figure given above. In

Plate V. At the head of the Road Branch is a small open basin, Zone V. Conditions here are much more like those on the Main Water than farther down the Road Branch.

To face page 34]

Plate VI (a). A close-up view of one of the deep pools with sheer banks that are a feature of the lowest part of the Horokiwi.

Plate VI (b). On the Road Branch the pools are much smaller and often run round a rocky nose, as in this picture.

the bottom fauna of a stream such as the Horokiwi one would often find a hundred or more different kinds of animals all living in the part of the stream and in the type of water where they find conditions most closely suited to their needs. Although the number of different kinds of animals is so great, many of them are either very scarce or closely restricted to a particular part of the stream or to a special type of stream bed. In most streams by far the greater part of the bottom fauna comprises a relatively few types, and in the Horokiwi about 98 per cent of the fauna consists of the following forms, most of which have been described and illustrated in " Field Notes for the Freshwater Naturalist," by P. Dickinson, recently published as Dominion Museum Handbook No. 3.

THE MAIN BOTTOM-FAUNA ANIMALS

CADDIS FLY LARVAE (Trichoptera)

Many of these build portable cases in which they live. In the Horokiwi the most common forms include:

A group with spiral sand cases, *Helicopsyche.*

A group with cylindrical sand cases, *Pycnocentrodes* and *Pycnocentria.*

A group with cylindrical cases of a yellowish, horny material; other species of *Pycnocentrodes,* and *Olinga.*

All these forms are more common in the upper part of the stream than in the lower waters, and *Helicopsyche* is in fact almost absent from the lowest reaches of the stream, although it is very abundant in the upper waters.

In addition to these larvae which form cases in which to live there are several other caddis larvae which do not form cases, but which either wander freely among the stones in search of prey or else spin fixed nets in which they trap the food brought down to them by the current. The most numerous forms in the Horokiwi belonged to the genera *Hydropsyche* and *Hydrobiosis,* but none of them was as abundant as the cased kinds.

MAYFLY NYMPHS (Ephemeroptera)

The most important of these were a number of very similar species belonging to the genera *Deleatidium* and *Atalophlebia.* These agile, flattened insects move freely over and among the stones of the stream bed. They are found in all types of water and in all parts of the stream. They are the most widely distributed of all the animals in the bottom fauna of the Horokiwi. In the lower waters, where the cased caddis larvae are least abundant, these mayflies are often the most numerous animals in the bottom fauna.

The only other mayfly of any importance in the Horokiwi is *Coloburiscus.* This is only found commonly in very rapid water, but occurs, under these conditions, in all parts of the stream.

MIDGE LARVAE (Chironomidae)

This is a large group of insects, some of the best known of which are the large red larvae (often called bloodworms) which are frequently common in stagnant water and rich organic mud. In the Horokiwi, as in most clear, rapid streams, the more numerous, although less conspicuous, forms are small green larvae (often less than a quarter of an inch long), which live in fine silken galleries on the upper surface of stones, particularly in fairly quiet, shallow water. They were most abundant in the upper half of the Main Water, although in certain favourable seasons they spread up and down stream from this area.

BEETLES (Coleoptera)

Although there are many kinds of water beetles in New Zealand, there is only one group which is common in the Horokiwi and similar streams. This is the family Parnidae. The larvae are small (rarely exceeding a quarter of an inch in length), and cylindrical in shape, and live in the sand and gravel of the stream bed in quiet or sluggish water. They are present at all times of the year. The adult beetles, which appear in December and January, do not swim, but crawl sluggishly over the stream bottom and over damp ground along the stream margins. They are black and about three-sixteenths of an inch long.

FRESHWATER SNAILS (Mollusca)

Although other species occur in small numbers, the only abundant water snails in the Horokiwi are those belonging to the genus *Potamopyrgus*. These are small, dark-coloured animals rarely more than a quarter of an inch long. They are very abundant in quiet pools and backwaters in the lowest part of the stream, but rapidly become less numerous farther upstream.

WORMS (Oligochaeta)

There are several kinds of earthworms which live under wet conditions, and often inhabit stream beds in considerable numbers. In the Horokiwi several of these are found abundantly, burrowing in the sandy bed of quiet pools in the lower reaches of the stream. In other parts of the stream and in other types of bed they are present in much smaller numbers.

WHICH DO THE TROUT EAT?

Although the various animals listed above make up in varying proportions the great bulk of the bottom fauna of the Horokiwi, they do not all contribute equally to the food supply of the trout. If other factors did not affect the situation, those animals which were most numerous in the bottom fauna would be most freely eaten by the trout. In actual practice we find that there are

great differences in the extent to which the trout eat the various animals. These differences depend on the habits and other characteristics of the bottom fauna animals and not merely on their abundance. From the studies made in the Horokiwi and elsewhere, certain simple principles have emerged which control the degree to which an animal is eaten. These principles may be set out briefly as follows:

Habits: Trout depend largely on sight to detect and catch their prey. As a result, the more conspicuous an animal may be, the more likely is it to be taken by a trout. An animal which lives normally on the tops of stones is obviously more likely to be eaten than one which stays on the underside of the stones or which burrows into the sand and gravel. An animal in movement is more easily seen than one which remains still, so that an active insect which is in frequent motion is more likely to be eaten than one which rarely moves.

Size: A trout swallows its food whole. There is therefore an obvious upper limit to the size of animal on which a trout can conveniently feed. There is also a lower limit to the size normally eaten. This may be ascribed to the fact that to obtain the same amount of food a trout must eat more small animals than large ones. As a result, if the food animals are smaller than a certain size, the trout needs so many to supply its needs that it cannot obtain them without an excessive expenditure of time and effort. As a result of these two limits trout of any particular size will normally only eat animals within an appropriate range of sizes. The size of the animals in this selected range naturally increases with the size of the trout.

Structure: The principle which is referred to under this head is not quite as obvious as those previously described, but research has shown that it is very generally applicable to trout and similar fish. This principle is that a large trout is more capable than a small trout of swallowing an animal encased in a hard protective shell. This is an effect of considerable practical importance, since quite a number of the bottom fauna animals, such as snails and cased caddis larvae, do possess these hard protective shells. It is not possible to fix a definite size and to say that trout of greater size will eat protected animals while smaller trout will not. But, as a rough rule, it can be said that the change in feeding ability generally seems to happen at lengths between 4 in. and 8 in.

Application of these three principles gives us a clear indication of the extent to which the different animals in the bottom fauna of the Horokiwi are likely to be eaten by trout of various sizes. Three groups of animals can be distinguished:

(*a*) Those which live largely on the tops of stones or which move about actively. These are all freely eaten by the trout at some period in its life. They include all the cased caddis larvae, the mayfly nymphs of the

Fig. 7. The animals which live on the tops of the stones are freely eaten by the trout, but those which burrow below the surface are rarely or never eaten. When small the trout eat small soft-bodied insects, but when large they eat snails and larger insects with hard cases. The figure shows some of the commonest animals of the Horokiwi in their usual positions—A, B, C: caddis larvae, *Pycnocentria, Pycnocentrodes, Helicopsyche*; D, snail, *Potamopyrgus*; E, Mayfly nymph, *Deleatidium*; F. Midge larva (Chironomidae); G, Beetle larva (Parnidae); H, Earthworm (Oligochaete).

Deleatidium group, the midge larvae, the snail *Potamopyrgus,* and the adults of the parnid beetles. All these animals form, at some stage, a greater proportion of the trout food than of the bottom fauna.

(*b*) Animals of less active habits which appear occasionally on the surface of the stones. The principal forms in this group are some of the caseless caddis larvae, such as *Hydropsyche,* and perhaps the mayfly *Coloburiscus.* These are found to be, at the most, about as abundant in the trout food as in the bottom fauna.

(*c*) Burrowing animals, rarely accessible to the trout. The most important of these are the larvae of the parnid beetles, and the earthworms. Under normal conditions they are virtually never eaten by trout.

In practice none of the animals in group (*b*) is ever very numerous in the bottom fauna. Consequently, the food of the trout consists very largely of the animals in group (*a*). Within this group the effects of size and structure play a large part in determining which animals form the main foods of trout at any particular age and season. The young trout in the first few months of life can only eat soft-bodied forms of very small size. In the Horokiwi these are largely midge larvae, and small (*i.e.*, young) mayfly nymphs. As the trout grow the chosen size also increases, and as a result the midge larvae very soon disappear from the food. The mayflies, on the other hand, being much larger than the midges when full grown, continue to form an important food for the trout.

Towards the end of their first year the trout reach a size sufficient to enable them to deal with the animals with hard cases. This opens up to them very extensive additional sources of food. Particularly important are the cased caddis larvae, which have habits which make them freely accessible to the trout, and which form a very large proportion of the bottom fauna, particularly in the upper reaches of the stream. We find, therefore, that from this time onwards these caddis larvae and, to a lesser extent, the snails and adult parnid beetles form a very large part of the food of the trout, although mayfly nymphs are also still freely eaten. The size effect becomes important again at this stage, although it is now working in the opposite direction to that which we saw when the fish were small. The trout in the second and later years (from 8 in. upwards in length) need to feed on relatively large food animals, generally at least a quarter of an inch long. All the important cased caddis, except *Olinga,* have life-cycles which take one year for completion. The adult flies hatch some time between October and January, depending on the particular species concerned. These lay eggs, from which the young larvae, less than one twenty-fifth of an inch long, soon hatch. The larvae grow slowly at first, and it is some months before they are sufficiently large to be taken by trout big enough to deal with their hard protective cases. These larvae, therefore, although they are numerous at almost all seasons, only form a significant part

of the trout food during the period, September to January, when they are large enough to be eaten. The other common cased caddis, *Olinga*, seems to have a two-year life-history, so that large larvae are present at all seasons. As a result, this caddis is freely eaten by the larger trout throughout the year. Another interesting contrast among the hard-shelled animals is provided by the adult parnid beetles. These also are only eaten during a short season in December and January. In this case the limitation is caused by the fact that it is only at this time that the adult beetles are present in the stream. At other seasons they are in the larval and pupal stages, which are not available to the trout. The other common hard-shelled form, the snail *Potamopyrgus,* is eaten throughout the year in those parts of the stream where it is abundant.

As a result of the effects of the three factors of habits, size, and structure we see that the principal components of the trout food in the Horokiwi vary during the life of the trout and between the seasons in the following way:

FIRST YEAR:	First few months	Midge larvae and small mayfly nymphs.
	Rest of year	Mayfly nymphs.
LATER YEARS:	September–January	Cased caddis larvae (all types). Mayfly nymphs. Snails. Parnid beetles (December and January only).
	February–August	Cased caddis larvae (*Olinga* only). Mayfly nymphs. Snails.

Although the greater part of the food of the trout consists of these forms, many of the other bottom fauna animals are also eaten in smaller numbers. Occasionally individual trout will be found feeding heavily on some of these other types.

TROUT COMPETE FOR FOOD

It is evident from these results that the food taken by the trout from the bottom fauna is restricted to a relatively small group of animals. These few kinds of animals must therefore yield most of the 14 tons which the trout derive from this source. As pointed out earlier, this amount must be even more than seventy times as great as the average total quantity of these particular animals which is present in the stream at any one time. This fact, in itself, suggests that there may be serious competition for food among the Horokiwi trout, although it is interesting to note that owing to the effect of

the factors discussed in the preceding pages there is relatively little competition for food between first-year trout and older fish. The mayflies of the *Deleatidium* group are virtually the only food animals eaten by trout at all stages, and even they are relatively unimportant to the older fish.

Further evidence of the way in which competition for food limits the growth of trout in the Horokiwi can be found if we compare the food requirements of the trout with the amount of bottom fauna in the various zones of the stream. In the first place we find that, as a rule, the amount of bottom fauna present is least in the zones where the density of the trout stock is greatest and that it increases as the trout stock decreases. This in itself suggests that the depredations of the trout have a large effect in limiting the quantity of bottom fauna which is able to develop. Further study shows us that, as a result, the amount of the bottom fauna which is needed for the support, or maintenance, of the trout is greatest in proportion to the total amount present in the zones where the density of trout is greatest. Since, as we have already seen, the maintenance needs can be regarded as the first charge on the food a trout eats it follows that the amount of excess food which can be used for growth is least where the trout stock is most dense. This leads again to the final result, which is borne out by the results of the investigation, that the rate of growth of the trout is least in the zones where the density of trout is greatest, and that it increases as the density decreases. Certain complications are introduced when both the Main Water and Road Branch zones are included in the one comparison. These may be due in part to the greater size of the Main Water and to the greater abundance in its bottom fauna of animals rarely eaten by trout, such as parnid beetle larvae and earthworms. The general comparison holds very closely despite this, and it may be illustrated by the following simple table which compares the four Road Branch zones:

ZONES	IIR	III	IV	V	
In these zones the average density of the trout stock was . .	110	200	320	200	lb. per acre.
The average density of the bottom fauna was . . .	40	25	23	40	,,
This is least when the trout are most dense, and *vice versa.*					
The food used for growth was this many times that used for maintenance . . .	2·2	1·7	1·3	1·8	
This also is least where trout are most dense, and *vice versa:*					
The average weight of a two-year-old trout was . . .	10	7½	6	8	ounces.
This again is least (*i.e.*, growth is slowest) where the trout are most dense.					

These comparisons therefore, seem to lead us inevitably to the conclusion that there is, in the Horokiwi, vigorous competition for food among the trout, so that the rate at which they grow and the size they reach depends upon the amount of food they can get, and that this in turn depends upon the number of fish which have to share such food as is available.

Chapter 6: THE NATURAL ENEMIES

We have seen in a previous chapter that about 97½ per cent (39 out of 40) of the trout fry hatched in October in a normal year have died by the following January, and that thereafter about four out of every five survivors die in each subsequent year. In the work now being discussed it was not possible to follow up these facts by examining in detail the causes of the deaths. Many of them were probably due to the various natural enemies which frequent most trout waters. In the Horokiwi, as in many other streams, the most obvious of these enemies are the eels. Although two kinds of eels are found in New Zealand rivers the only ones which grow to sufficient size to feed freely upon trout or other small fish are the females of one species, the Long-finned eel. Recent studies have shown that in most waters the number of eels present is largely decided by the amount of cover available to them. Eels are most numerous where abundant cover is provided by weed beds, under-cut banks, accumulations of brushwood, &c. At the other extreme, eels are scarce in rivers which flow over open shingle beds. In most parts of the Horokiwi cover is fairly plentiful, but not excessively so, and consequently we find an intermediate population of eels. The density of the eel population is probably about 400–500 lb. per acre, which is roughly twice the density of the trout population. Only about a fifth of this consists of eels large enough to eat small fish. It was not possible to make detailed estimates of the quantity of trout an eel stock of this density would eat, but it cannot be doubted that they would take some considerable number of small fish.

The only other enemies of trout which are at all apparent are the fish-eating birds. These, by their conspicuousness, are apt to seem more important than their depredations warrant. The most widespread of them is the Black Shag. This was often seen in the Horokiwi Valley, but generally when passing between fishing grounds in the Porirua Harbour and roosts in the hills behind the Horokiwi. They were seen fishing in the Horokiwi itself on very few occasions, and it is unlikely that they take any appreciable quantity of trout there.

A number of other fish-eating birds were occasionally seen on the Horokiwi, but none of them was frequent or numerous enough to give it any practical importance. They included the White-fronted and Caspian Terns, the Kingfisher, and the Bittern. The Blue Heron was common on the Pauatahanui Inlet, but was never seen up the stream.

It seems, therefore, that at present we cannot say what part the various natural enemies play in bringing about the death of so many trout each year. But of the obvious possible enemies the Long-finned eel seems the only one likely to be of much importance on the Horokiwi.

Chapter 7: THE WEATHER

TEMPERATURE

The two features of the weather which have the greatest effect on trout are the temperature and the rainfall. Like most other fish, trout thrive best within certain limits of temperature. For the brown trout these limits are roughly 45° F. to 65° F., although they will survive in temperatures ranging from 32° F. (freezing-point) to about 80° F. The extreme temperatures recorded in the Horokiwi were 42° F. and 70° F., but even these limits were rarely reached, and the extreme monthly averages were 45° F. in July and 67° F. in January. We see, therefore, that at almost all seasons the temperature of the Horokiwi lay within the limits best suited to the trout. This favourable temperature range may help to produce the very rapid rate of growth which occurs in the Horokiwi, since it is neither cold enough in winter nor hot enough in summer to cause growth to be checked.

RAINFALL

While rainfall, in itself, has no direct effect on trout, it may have important indirect effects, since it controls the occurrence of floods and droughts. Both of these can, in some waters, play an important part in determining the size and growth of the trout stock. Waters which dry up completely in times of drought are not numerous, but they can be found in many parts of New Zealand, and where they exist the fate of the trout population may be largely controlled by the occurrence of wet or dry seasons. Floods, on the other hand, are important in many parts of New Zealand, where unstable shingle-bedded rivers are so common. The Horokiwi is a good representative of this type of water, and it was therefore rather fortunate that the period during which it was studied included both dry and wet spells, so that the effects of flooding could be directly measured.

The first two years, 1939 and 1940, were both normal, dry years. The total annual rainfalls at Plimmerton, just outside the Horokiwi drainage basin, were respectively 39 and 42 in., as compared with the average for many years of 39 in. In 1939 there were only two floods of any height, and both of these were of short duration and did little damage. In 1940 there were no serious

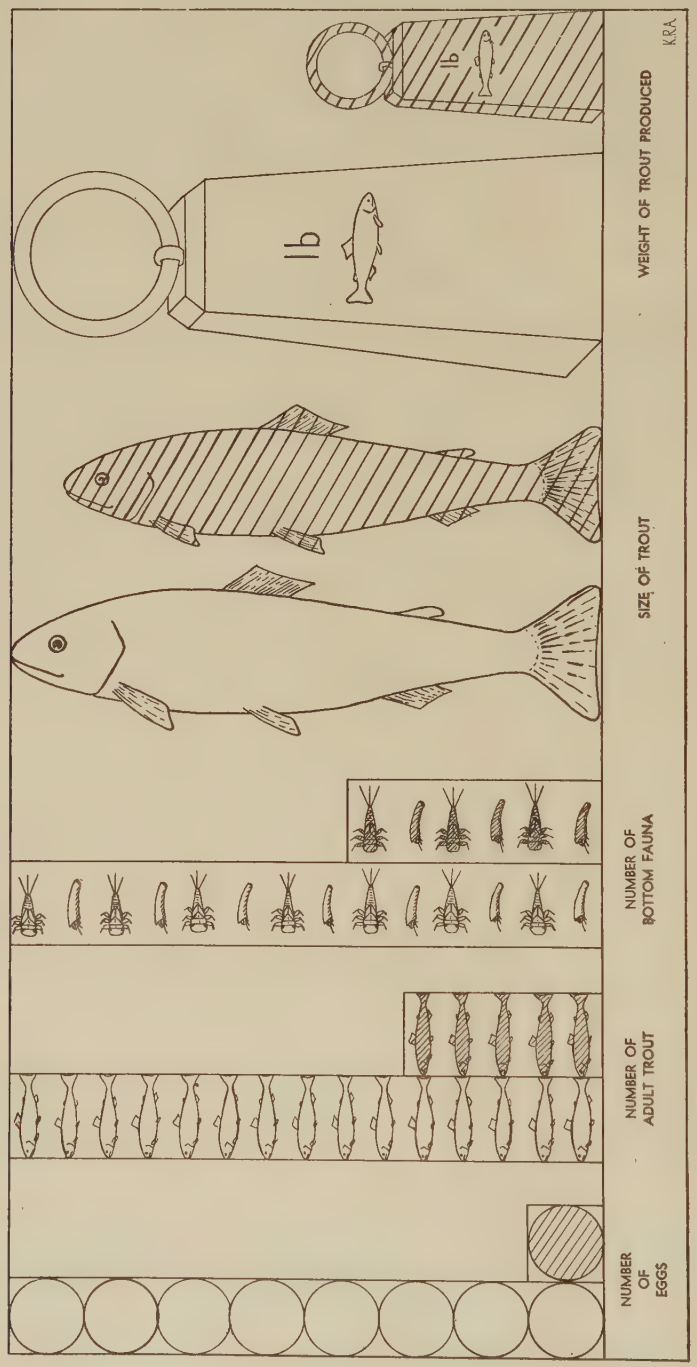


Fig. 8. The severe floods of 1941 in the Horokiwi caused a reduction in the numbers of both eggs and adult trout, as well as in the quantity of bottom fauna. The reduced amount of food caused a decrease in the rate of growth and so in the total weight of trout produced in the stream. In the diagram the normal condition (white) is compared with that following the 1941 floods (shaded).

floods. By contrast, 1941 was an extremely wet year with a total rainfall of 58 in. A severe flood in February lasted for an unusually long time, and caused a great deal of disturbance of the stream bed. This disturbance caused the bed to become very loose and unstable, so that it shifted easily in later small floods. These smaller floods continued at intervals throughout the year, and were particularly prevalent in July and August. The wet weather finally culminated in another very severe flood early in October.

FLOODS DO SERIOUS HARM

We have already seen that the great disturbance of the shingle in 1941, during and after the spawning season, caused abnormally high losses of trout eggs and young fry. This was not the only harmful effect which the flood had on the trout. There seem to have been quite substantial losses of older trout, also as a result of the floods. In October 1941, after the floods, the number of older trout in the various parts of the stream was generally between one-quarter and a half of that of fish of similar age in the previous October.

In addition to the direct reduction in the number of trout, there was also a reduction in the food supply. This in turn had harmful effects on the growth and condition of the trout. In the stream as a whole the floods reduced the quantity of bottom fauna to rather less than half of what it had been in the previous year. In Zone II, where the damage was most severe, the reduction was even greater, to less than one-quarter of the original amount. As a result of this reduction in food supply the growth of the trout was definitely reduced in 1941. In Zone II, for instance, the fish hatched in October 1940 were in May 1941 only three-quarters of the weight of the corresponding fish a year earlier. In other zones where flood damage was less there was a similar, although smaller, reduction in growth. The fish of earlier year-classes had done most of their growing before the floods occurred and were therefore less affected, but, even so, they also showed some check in growth. The condition of the trout in the Horokiwi was found to be normally very good; the condition factor, which measures the relation between the weight and the length of a fish, was generally between 120 and 130 for the younger fish. In 1941 the shortage of food due to the floods brought about a definite reduction in condition, and the condition factors were generally about 5 per cent below the normal values.

Thus in 1941, as a result of the floods, the trout were not only less numerous than in previous years, but they also grew more slowly and were consequently lighter than normal. As a result the total weight of the stock was less than before. This must have led to a reduction in the amount of food needed by the trout population for maintenance. It is interesting to observe that the bottom fauna was so greatly reduced that, in spite of this, the amount of

food which could be used *for growth* by each *individual* fish was reduced sufficiently to cause a decrease in the growth rate. This is further evidence in support of the conclusion which was reached in a previous chapter that, in the Horokiwi at any rate, the rate of growth is largely controlled by competition among the fish for the limited amount of food available.

The reduction in number and rate of growth of the trout must have caused a corresponding reduction not only in the weight of the stock in 1941, but also in the quantity of trout flesh produced by growth during the period affected by the floods. The premature ending of this work late in 1941 prevented this period from being followed to its conclusion, but a comparison can be made between the period May to October 1941, when the floods had their maximum effect, and May to October 1940, before the floods occurred. In 1940 the amount of new trout flesh produced in this period was about 1,500 lb., but in 1941 it was only 400 lb., or less than one-third of the normal. This three-fold reduction in the quantity of trout which the Horokiwi produced by growth in 1941 compared with 1940 can be safely ascribed to the effect of the heavy and continued floods of that year.

Chapter 8: THE ANGLER

HOW MANY FISH?

The records of angling catches in the Horokiwi have been carried through continuously from 1939 to the present day. In this time three main periods can be distinguished:

From 1939–40 to 1941–42 conditions were normal, or only slightly affected by the war. Fishing was carried on vigorously, and about 200 to 350 fish were taken in a season.

From 1942–43 to 1944–45 the amount of angling was very greatly reduced, largely as a result of petrol rationing. The number of fish killed in a season was between 30 and 60.

From 1945–46 onwards conditions rapidly reverted to normal. The angling catch rose again to about 150 fish. The decrease from the pre-war normal seems to be largely due to the absence of a few anglers who had fished the Horokiwi very regularly in earlier years.

Throughout the period studied much more angling was done in the Lower Waters (Zones I and II) than in the Upper Waters (Zones III, IV, and V). The only exception to this was in 1943–44, when, although angling was generally at a minimum, one enthusiastic angler fished the Upper Waters very heavily for a time. Although this was the only season in which the usual condition was reversed, there has been a tendency during the whole period for the proportion of fish taken in the Upper Waters to increase. At the beginning of the study only about 5 per cent of the fish were taken in the Upper Waters, but by the end this proportion had risen to about 25 per cent. The greater popularity of the Lower Waters is probably due partly to the easier fishing provided by the larger size of the stream and the absence of trees, and partly to the greater average size of the fish. On the other hand, trout have almost always been more abundant for the angler in the Upper Waters, and this is probably causing more and more anglers to be willing to deal with the more difficult conditions there.

RATE OF CATCH

In the Lower Waters the average rate of catch has been about 0·6 fish per hour—that is, on an average, an angler had to fish 1 hour 40 minutes for each fish he caught. In the Upper Waters the rate of catch has been appreciably

higher at 0·8 fish per hour, or one every $1\frac{1}{4}$ hours. It is noticeable that during the middle of the period studied (*i.e.*, from 1942–43 to 1946–47) there was a time when the rates of catch were much lower than the average figures given above. We have seen earlier that floods in 1941 caused very serious losses to the trout stock, and that the 1941 year-class in particular was reduced to about one-fifth of the normal numbers. It is precisely the year-classes that were reduced in numbers by the flood, and their immediate descendants, which would provide the bulk of the takeable fish during the seasons when the rate of catch was low. There can be little doubt, therefore, that the period of poor fishing which began in 1942 was due in large part to the floods of 1941. It is worth remembering that this was not prevented by the hatchery liberations of 1941, despite the fact that these were the largest in the Horokiwi for many years and twice as great as the average. During the same period a large military camp was set up close to the mouth of the Horokiwi, and there are local reports of extensive poaching at times by men from the camp. This may have helped to produce the bad years referred to above, but it is likely that its effect was, at the most, subsidiary to that of the floods. It is clear that the quality of the fishing declined throughout the length of the stream, and there is no suggestion that any area of the stream, other than the lower part of the Main Water, was affected by the poaching.

The widespread diary scheme which has been in operation in New Zealand during the last few years has given results which enable us to compare the Horokiwi with other trout waters in all parts of the country. *This has shown that most waters in the "fair to good" category give rates of catch of between half and one fish per hour, or one to two hours per fish. The average over the whole country is about a fish every one and a half hours. It is clear that the Horokiwi is therefore, in this respect, a very typical trout stream.* The rate of catch in all parts is well within the usual range, while the average for the whole stream is very close to the average for New Zealand as a whole.

SIZE AND AGE OF FISH

The largest fish recorded from the Horokiwi during this study was one of $5\frac{1}{2}$ lb. taken in the Main Water in the 1945–46 season. This was quite an exceptional fish, and very few others of more than $2\frac{1}{2}$ lb. have been caught. In the Lower Waters the average weight has been steady at slightly under 1 lb. for the whole of the period. In the Upper Waters the average has been about 13 oz., with very few fish of more than $1\frac{1}{2}$ lb. This difference is only to be expected, since, as we saw in an earlier chapter, the rate of growth is very much less in the Upper Waters than it is in the Lower Waters, and consequently the maximum size which a fish normally reaches is also less. This was illustrated in Fig. 5, which also shows that, while the average fish in the

Lower Waters becomes takeable in its second year, many of those in the Upper Waters do not reach this size until four years old. It is an obvious result of this difference that the proportion of under-sized fish in the stock is very much greater in the Upper Waters than in the Lower. This is reflected in the anglers' catches. In the Upper Waters an angler averages seventeen under-sized fish for every ten takeable fish he catches. In the Lower Waters the proportion is only 11 to 10.

The angler is only interested, directly, in the number and size of the fish he catches. But, to be able to place our fisheries conservation practices on a sound basis, we must understand how these fish are produced and how they are related to the rest of the stock. We have already seen that in the Lower Waters fish become takeable in their second year, but that in the Upper Waters few become takeable before their fourth year. If we analyse the position in the Lower Waters in more detail we find that, during the first two months of the season, about two-thirds of the catch of takeable fish consists of fish in their third year, most of the rest of older fish, and very few second-year fish. By the middle part of the season many of the second-year fish have become legally takeable, and they now form half the catch, most of the rest being third-year fish. By the last two months still more second-year fish have become takeable, and they comprise three-fifths of the catch, while there are very few older fish. Owing to these changes during the season the composition of the entire season's catch may vary from year to year according to the relative amounts of angling done in the different parts of the season. *It seems that, as a rule, rather over one-half of the season's catch consists of third-year fish, while the second-year fish form about three-quarters of the remainder.* In the Upper Waters a rather similar position exists, except that, throughout, the fish are one year older.

PROPORTION CAUGHT BY ANGLERS

Thus we see that up to the end of the first year in the Lower Waters, and the second year in the Upper Waters, no deaths are due to angling. In the following year some fish are removed by angling, although they only become takeable during the season. During the 1940–41 fishing season about 900 second-year fish died in the Lower Waters; of these the anglers took 80, or about one in eleven. In the Upper Waters angling caused the deaths of only 2 out of 600 third-year fish which died during the season. All older fish are takeable throughout the season and all year-classes can therefore be considered together. In the Lower Waters angling caused 200 out of the 600 deaths of such fish in 1940–41, or about one-third. In the Upper Waters the angling deaths were 13 out of 120, or about one in nine. *To sum up the over-all effect, we can say that in the Lower Waters out of each 100,000 fry only*

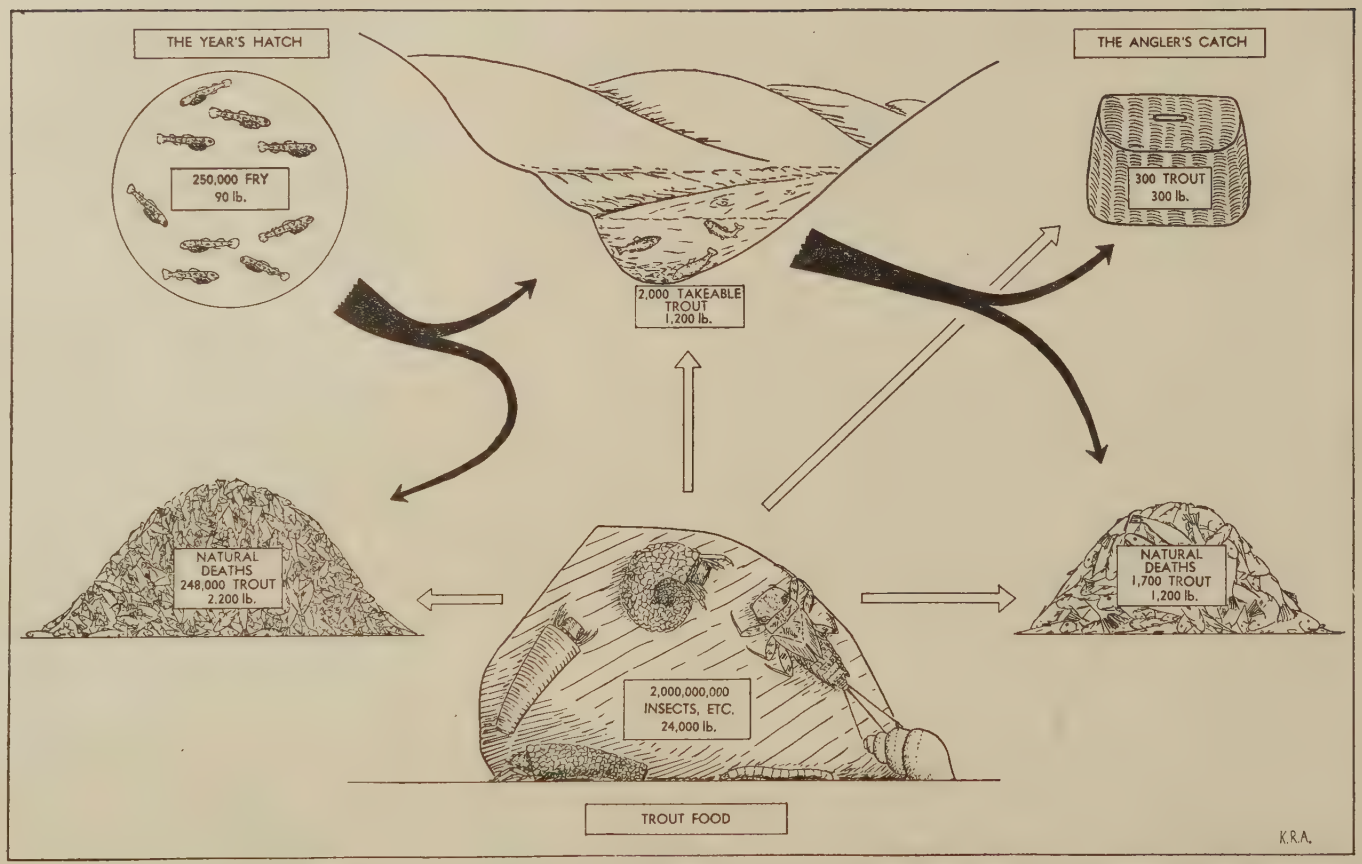


Fig. 9. In a normal year 250,000 trout fry hatch in the Lower Waters of the Horokiwi, but only 2,000 survive to reach takeable size. Of these, only 300 are caught by anglers, the other 1,700 die natural deaths. To grow and maintain this trout stock, which yields about 300 lb. of fish to the anglers, over ten tons of food are needed.

about 800 are left alive when the year-class first begins to be takeable early in its second year, and that only about 120 of these are caught by anglers; the other 99,880 die from other causes. In the Upper Waters the position is even more extreme; of each 100,000 only 200 survive until the year-class begins to be takeable, and only 4 are caught by anglers. The difference between the two regions of the stream is, as we have seen, partly due to the greater age at which the fish become takeable in the Upper Waters as a result of their slower growth. It is also due to the smaller amount of angling, which removes only one in fifty of the takeable fish, compared with one in seven in the Lower Waters.

It is perhaps even more helpful, though not quite so simple, to consider the weight rather than number of the trout caught by anglers, and to compare it with the total weight produced in the stream. We saw in an earlier chapter that while the weight of trout flesh produced by the growth of the fish in any year-class continues to increase throughout life, the total weight of the fish which are still alive rises to its greatest value some time during the second year, and decreases thereafter. We also saw that, even at its maximum, the weight of the stock is only about one-third of the weight which has been produced up to that time. In the Lower Waters trout are first takeable early in their second year. At this time the weight of living trout is about 800 lb. out of a total weight of 3,000 lb. which has so far been produced. Thus about 2,200 lb. of trout have been lost through natural causes before angling begins to have any effect. By the end of the second year (*i.e.*, after the first angling season) there remain 550 lb. of living trout out of a total production up to this time of 3,550 lb., so that the trout which have died during their first two years weighed 3,000 lb.; 800 lb. being the weight of the fish dying in their second year. Of this amount, anglers have so far taken only 45 lb.

Many of the second-year fish which are caught by anglers are under-sized and have to be returned, and this greatly restricts the weight of fish of this age which anglers remove. In all later years virtually every fish in the Lower Waters is takeable, and therefore the angling catch is much greater in proportion to the quantity of fish present in the stream. There is no real difference between these later years in the proportion of the fish which anglers take, and these remaining years in the life of a year-class can therefore be considered together. By the time all the fish in the year-class are dead a total of about 3,750 lb.of trout flesh has been produced, 200 lb. in the third and later years. Since all the trout are now dead, this 3,750 lb. is also the weight of the fish which have died, and 750 lb. of this is the weight of fish dying after their second year. The weight of the angling catch of these three-year-old and older fish is slightly over 200 lb., giving a total angling catch of 250 lb.

To summarize these results:—

The total weight of trout flesh formed during the life of a typical year-class is 3,750 lb.

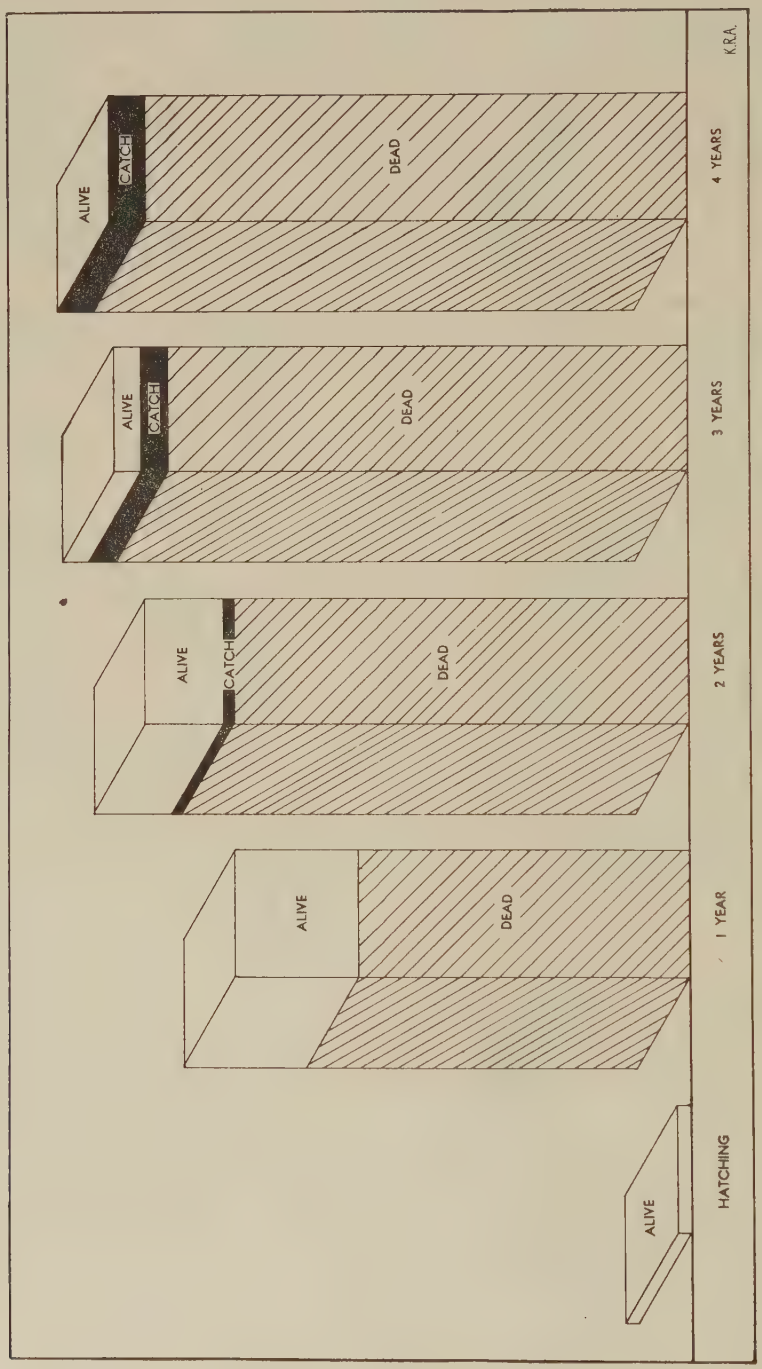


Fig. 10. As the trout in a year-class grow, the total weight of trout flesh which they have formed increases continually, at first rapidly, and then more slowly. The total weight of those still alive, on the other hand, only increases for a time, and then decreases again as the fish die off. In the Lower Waters of the Horokiwi most of the angling catch is taken in the second and third years. In the figure the height of the columns is proportional to the total weight of trout produced up to that age, and they are divided in proportion to the amounts which remain alive, or have been taken by anglers, or have died natural deaths.

Of this amount, 2,200 lb. (58 per cent) is lost by natural deaths before any fish are old enough to be takeable.

A further 1,300 lb. (35 per cent) die naturally after the year-class has begun to be takeable.

Only 250 lb. (7 per cent) are caught by anglers.

In the Upper Waters events are rather similar, but, as we have seen, the quantity taken by anglers is greatly reduced both by the smaller amount of angling and by the greater age the fish must reach before they become legally takeable. By the time the fish first become takeable, in the third year, the total production of 1,250 lb. is virtually complete, and 800 lb. (65 per cent) has already been removed by deaths from natural causes. During the third year further deaths reduce the surviving stock to only about 85 lb., or 7 per cent of the total production. Of the 1,165 lb. which have so far been lost the anglers have only taken about 1 lb. During the remaining years, while the last 85 lb. is being removed by death, anglers take about 10 lb. *Thus in the Upper Waters of the Horokiwi anglers obtain less than 1 per cent of the total weight of trout which is produced.*

Since the quantity taken by anglers is only a very small proportion of the trout produced in the Horokiwi it is interesting to carry the comparison a stage further and see how it is related to the amount of food eaten by the trout. Of the 32,000 lb. of food which the Horokiwi trout eat in a year, about 24,000 lb. is eaten by the fish in the Lower Waters, and the remaining 8,000 lb. by the Upper Water fish. A large part of this food is eaten by trout in their early years, when they are growing very rapidly and need additional food for this purpose. In the Lower Waters nearly 15,000 lb. is eaten by trout in their first year, before any of them are taken by anglers. In the second year, during which anglers take about 45 lb. of trout, more than 6,000 lb. of food is eaten. In their first two years, therefore, the trout eat 21,000 lb. of food, or 87 per cent of the total quantity. This shows that nearly all the food has been used in producing the relatively small quantity of takeable fish from which the anglers draw their catch, and that less than one-twelfth of it is used to maintain the takeable trout and in their growth to greater size. In the Lower Waters the total amount of food eaten is about a hundred times the weight of trout caught in a year.

In the Upper Waters, where growth is slower and anglers less numerous, the contrast is even greater. Over 94 per cent of the 8,000 lb. of food which the trout eat in these waters is taken by fish in their first three years. The quantity of these fish caught by anglers is only about 1 lb. a year. In these waters only about 6 per cent of the food is therefore used to maintain and give further growth to the takeable fish and the total amount of food eaten is 600 times as great as the usual angling catch.

In view of the small proportion of the trout produced which goes into the angler's bag it is interesting to compare the yield the anglers obtain with that obtained from land under normal farming practices. Such a comparison must be made on the basis of yields from equal areas of water and land respectively. In the Horokiwi the anglers catch about 35 lb. and 3 lb. of trout per season per acre on the Lower and Upper Waters respectively. A good comparison can be made with the total weight of livestock produced on good average New Zealand land used for fattening lambs. Including the ewes, and the cattle necessary for good management, this averages about 335 lb. per acre per season. This is roughly ten times the angling yield from the Lower Waters and a hundred times that of the Upper Waters. It is, however, very close to the actual quantities of trout produced per acre in both parts of the stream. It seems, therefore, that a typical trout stream, such as the Horokiwi, actually produces just about as much meat as land under good farming management, but that the yield which man obtains from it is very much less on account of the great inefficiency of angling as a method of harvesting the crop.

Chapter 9: THE CONCLUSIONS

THE PURPOSE OF FISHERIES MANAGEMENT

In the opening chapter we considered a number of questions which would have to be answered if we were to have a proper understanding of the relation between a trout stock, its food supply, and the yield obtained by anglers. In later chapters we have discussed the answers to these questions which were obtained for the trout of the Horokiwi between 1939 and 1941. It now remains for us to examine these results and to try to obtain from them information as to the steps which can best be taken to maintain and improve the yield of trout to the anglers in the Horokiwi and, if possible, elsewhere.

The main object of the angler is to catch fish. The greater the quantity of fish he catches the happier he is. Some anglers prefer to catch as many fish as possible, and are less concerned about the size of each fish. Others would rather catch a few large fish. Probably the most generally acceptable measure of the angler's bag is its total weight, whether made up of many small fish or of a few large ones. This being so, it seems that as far as possible we should try to manage our trout streams so that each angler can get the greatest possible weight of trout from them. If each angler is to get this result the total combined take of all anglers fishing the stream must also be as great in weight as possible. We have seen that in the Horokiwi, which is typical of many other trout waters, there is vigorous competition for food among the trout. This means that if the number of trout in any part of the stream increases, the rate at which they grow will decrease. Consequently, although we can increase the *number* of trout in the stream by liberations, destruction of predators, and so on, we cannot increase the total weight unless we can also increase the amount of food available to the trout. In fact, because the increased number of fish will need more food for maintenance, there may actually be less food left for growth, and as a result an increase in numbers might actually lead to a decrease in total weight of trout produced.

The immediate aims of our attempts to manage trout stocks for the benefit of anglers should therefore be:

To increase the food supply, if possible.

To enable the angler to get the greatest possible proportion of the weight of trout produced in the stream.

To allow sufficient spawners to survive to produce enough trout to make full use of the food supply.

The results obtained in this study allow us to consider the probable effectiveness, both in the Horokiwi and in other trout waters, of the various methods of fisheries management commonly practised or discussed in New Zealand and elsewhere.

INCREASE OF FOOD SUPPLY

STREAM IMPROVEMENT

As practised in America and other countries, the main object of this work is generally to make the stream a more attractive habitat for trout by increasing the quantity of cover and making more pools. The scouring action of the stream is sometimes used to clear away a mud bed and expose clean shingle; this generally leads to a greater quantity of the insects upon which trout feed, thus increasing the food supply.

In New Zealand, where unstable shingle streams are so common, the greatest need is probably for greater stability in the stream bed. We have seen in Chapter 7 the extent of the damage which floods can cause in an unstable stream, both to the bottom fauna and, directly as well as indirectly, to the trout. There is good reason to believe that in many streams the amount of food which the bottom fauna can provide is limited for long periods by the action of floods.

It is unfortunate that the size of the works necessary to stabilize a stream-bed generally puts them beyond the means of fisheries organizations. To be effective these measures must often extend from the stream itself and take in also the land which it drains. Although widespread action, other than co-operation and encouragement for the more appropriate authorities, is obviously impractical for fisheries interests at present, *there are probably certain critical areas, particularly in nursery streams, where it is not beyond the means of an acclimatization society to undertake stream stabilization work, perhaps in co-operation with local landowners.*

FERTILIZATION

Much publicity has been given in recent years to the addition of fertilizers to natural waters as a means of increasing the production of fish. The basis of the method is, of course, that the fertilizers promote the growth of the minute uni-cellular plants. These plants provide food for the insects of the bottom fauna in streams and for the tiny floating crustacea of the plankton in lakes. The increased quantities of bottom fauna or plankton which result provide additional food for the fish, and so lead to an increased production.

While the theory of the method is sound, its practical application is fraught with many limitations. These were fully discussed in Freshwater Fisheries Circular No. 1 published by the Marine Department in 1946. These limitations arise mainly in two ways. The amount of plant growth may be limited by factors other than the supply of nutrients, or the growth of bottom fauna or plankton may not be controlled by the amount of plant food available. In such cases no appreciable result can be expected whatever the quantities of fertilizer added.

The other limitation, and probably the more usual one, is economic. This appears when the cost of the fertilizer necessary to produce results is balanced against the resources available and the return in improved fishing which can be achieved. In some small shallow lakes a useful return can sometimes be achieved at reasonable cost, although even here much of the fertilizer is lost by absorption in the bottom mud. In large lakes great quantities of fertilizer must be added before the proportion of nutrient salts in the water is appreciably increased. The cost of this is generally far in excess of the funds available for a single aspect of fisheries management.

In streams any fertilizer added is liable to be lost not only by absorption in the stream-bed, but also by being carried away to the sea. The quantities required to produce a useful effect are therefore very great in this case also. Little experimental work has been done on the fertilization of streams, but it seems that, even in small streams like the Horokiwi, the addition of a ton of fertilizer annually would only affect a few hundred yards of stream.

BACKWATERS

Proposals have sometimes been put forward for the construction of backwaters or lagoons connected to the main stream by drains. It is suggested that insects and other invertebrates would multiply profusely in these places, and drift out, providing a constant replenishment for the stream bottom fauna. In practice the value of such a method is highly dubious. The animals which inhabit standing waters of the kind suggested are adapted to these conditions, and very few of them can establish themselves and survive in a running stream. Thus any which do drift out into the stream will be lost unless they are quickly eaten by fish, and they will not help to populate the stream. The number which will drift out in this way will also be small since by their very habits these animals tend to keep away from moving water and so would avoid the outlet of the backwater.

Therefore, although increasing the food supply would probably help to increase the production of trout in streams like the Horokiwi, none of the methods so far suggested or employed overseas is economically available under New Zealand conditions, except on a very small scale.

LIBERATIONS

QUANTITIES AND COSTS

In New Zealand the liberation of hatchery-produced fry and fingerlings has been traditionally the main method used in many districts in the attempt to maintain or build up trout stocks. The Horokiwi was selected for this work as being typical in many respects of a large class of trout streams, and we have seen that in proportion to the amount of angling done there it has been stocked in recent years at a rate rather greater than the average for the Wellington district. Study of the effect of liberations in this stream will therefore give a good indication of their value to many other New Zealand waters.

The average number of fry liberated in the Horokiwi is about 15,000 annually. In a normally fine year the quantity of fry produced naturally is about 500,000, or more than thirty times the liberations. Even if we assume that the hatchery-produced fry survive as successfully as the natural ones, this means that only about one in thirty of the fish caught by anglers had its origin in the hatchery. At the time of this work anglers were taking about 300 trout from the Horokiwi each season. Evidently, therefore, not more than ten of these had been added by the liberations; the other 290 would have been caught in any case.

Study of the records of expenditure by acclimatization societies on hatcheries shows that at the period under discussion the production and liberation of 15,000 fry would have cost between £5 and £10. At the present time the cost of production of fry has risen still higher as the cost of labour and materials has increased. *Therefore, in the Horokiwi before the war, each extra fish which was put in the angler's bag by liberations had cost between 10s. and £1.* It becomes evident that in streams like the Horokiwi liberations on the usual scale make a very small addition to the angler's catch at a very high cost.

Liberations on this small scale are clearly insufficient to have any appreciable effect on the growth of fish. But, as already pointed out, *if liberations are increased to the point where they add significantly to the stock, there is a definite risk that increased competition for food may cause a reduction in growth rates and possibly even in the total weight of trout produced.*

IN FLOOD YEARS

It is sometimes suggested that liberations are necessary to maintain stocks in years of bad flooding. The severe floods of 1941 provided an opportunity of testing the truth of this idea on the Horokiwi. In that year floods reduced the natural production of fry to about 100,000. An abnormally large liberation added a further 30,000. Although the liberation was twice the normal size the quantity of fry in the stream was only about one-quarter of the normal,

Plate VII (a). The square-foot samples of stream-bed, which were taken to measure the bottom fauna, were dug up with a special scoop used by two workers, one pushing and one pulling.

Plate VII (b). To find out how many eggs were in the trout redds, and how many survived to hatching point, some redds were dug up with a shovel. A net set downstream caught the eggs and young fry as they were dug out.

Plate VIII (a). A general view of the valley of the Main Water, taken from about half-way up Zone II. In the distance can be seen the waters of the Pauatahanui inlet, which joins the open sea through the gap in the hills on the extreme right.

Plate VIII (b). In severe floods, such as that of 2 October 1941, the Horokiwi overflows its banks and spreads out over the surrounding fields. This picture is taken from almost the same point as the one above.

and, as we have seen, several years of poor fishing followed. About a quarter of the fifty fish of the 1941 year-class which were caught by anglers probably originated in the hatchery liberations. The liberated fish may have speeded up the recovery from the effects of the flood slightly, since they added about one-quarter to the breeding stock. On the other hand, the floods reduced the food supply so seriously that increased competition slowed up the growth of the trout considerably. This caused them to be smaller than normal at the time they reached breeding age, and so reduced the number of eggs they produced. The liberated fish, by increasing competition, must have increased this effect, and so helped to reduce the number of eggs each hen fish produced. This would have offset to some extent the gain to the breeding stock, and so to recovery which was made by the addition of the liberated fish.

FRY OR OLDER FISH

The results obtained on the Horokiwi help us to assess the relative advantage of using fry or older fish where a policy of liberating hatchery-produced fish has been decided upon.

The class of fish liberated should be that which will give the greatest return to the angler for each £1 spent on its production.

From what has been found out on the Horokiwi and overseas we can now say, roughly, how many fish of any age will have to be liberated to produce one more takeable fish in the stream. The number required will depend upon the age at which the fish reach takeable size. If, as is common, they reach this size when three years old, then, approximately:

1 takeable fish needs 5 two-year-olds,
or 25 yearlings,
or 1,250 fry.

The liberation of these quantities of fish will not add one more fish to the angler's catch; it will only produce one more takeable fish in the water. The quantity needed to add to the catch will depend on the amount of fishing, but will be at least several times the above figures.

There is another reservation which must be made. These figures assume that the yearlings and two-year-olds are, when liberated, the same size as the wild fish of that age, so that they reach takeable size after the same length of time. If they are smaller, they will take longer to become takeable, and more of them will die before reaching this size. A greater number will therefore have to be liberated to overcome this effect. In the Horokiwi, which is typical of a large class of waters, trout grow naturally considerably faster than they do in most hatcheries. In such a stream, therefore, the numbers of yearlings or two-year-olds needed would be greater than those given in the table. The numbers of fry are not affected in this way.

In New Zealand it is even more difficult to make a general statement about the relative costs of producing fry and older fish than it is about their relative survival values. Hatchery organization and staffing has varied greatly from district to district, and records have rarely been kept in a form which would allow relative production costs to be distinguished. Any decision as to the class of fish to be produced in a hatchery, if one is desirable, should therefore be based on the considerations of relative survival discussed above, and on the best local information available regarding production costs.

PREDATOR CONTROL

SHAGS AND OTHER BIRDS

We have seen that on the Horokiwi none of the fish-eating birds was sufficiently numerous to take any appreciable quantity of trout. A campaign for their control in this area would not therefore have added significantly, if at all, to the angler's catch. In some other New Zealand waters where these birds, and particularly shags, are more abundant, control measures might result in the saving of sufficient fish to affect the catch.

Vigorous competition for food, such as occurs in the Horokiwi, might be accentuated if the removal of predators allowed considerably increased numbers of trout to survive. The possibility must be recognized that in such cases predator control might lead to a decrease in average size. This would tend to offset the advantage gained by increasing the numbers of trout which survive to maturity.

EELS

The female Long-finned eel is much the most abundant predator on trout in the Horokiwi, and in many other New Zealand waters. Removal of these fish as completely as possible might therefore add considerably to the number of adult trout in the stream. Such an increase might tend to carry with it the risk of a reduced growth rate mentioned in the preceding paragraph. The position is made more complicated by the fact that the eels, particularly when young, feed largely on the same animals of the bottom fauna as do the trout. In the Horokiwi the weight of eels, mainly small, is about twice that of the trout. The removal of eels would therefore make available increased quantities of food for the trout and in this way the effects of excessive competition among the trout might be reduced or avoided.

Eel removal, like any other method of fisheries management, is only desirable if it produces a benefit to the angler's catch sufficient to justify the expenditure incurred. Present methods of eel removal, based largely on the use of baited traps, are not only expensive, if carried out thoroughly, but also take only the larger eels, more than about 26 in. long. *This means that, to keep down the*

population of eels of fish-eating size, the rivers must be trapped every three or four years. It also means that well over half the quantity of eels originally in the river still remains competing with the trout for food, so that the full amount of additional food is not made available for the extra trout.

It is apparent, therefore, that not only is more research required into the effect of eel removal on trout stocks, but also that, if it is to be an economic proposition, it will be necessary to develop means of removing eels of all sizes and not only those which can be taken with baited traps.

REGULATIONS

The enactment and enforcement of restrictive regulations constitute, with liberations, the chief methods of fisheries management practised in New Zealand.

The main effect of the regulations in force on the Horokiwi is to restrict the taking of fish to licensed anglers using one rod and line, with artificial fly, and to fix:

A close season from 1 May to 30 September,
A size-limit of 11 in.,
A bag-limit of 12 fish.

The last two of these regulations are the only ones which rest on a biological basis. The limitation to licensed anglers protects the privileges of those who provide the funds for the maintenance of the fisheries. The intention of the prohibition on all baits and lures except artificial fly is probably to reserve the water, without interference, for the pursuit of what is felt to be the most sportsmanlike method. This is a matter of taste and as such is outside the scope of the present biological inquiry. The close season, by preventing angling during the spawning season, makes easier the protection of the fish at a time when they are particularly vulnerable to poachers.

THE SIZE LIMIT

The regulation fixing the size limit is the most important of any in its effect on the angling catch and on the stock of fish in the stream. It is this regulation which determines the age at which fish can first be legally removed. It therefore directly affects the last two of the three immediate aims of fisheries management which were laid down on p. 57.

The first of these was that the anglers should be enabled to take the largest possible proportion of the weight of trout which the stream produces. We saw in Chapter 4 that the proportion of the total production which is available to anglers in the form of the surviving stock of fish varies greatly during the life of each year-class. It is at its maximum when the fish comprising the year-class are in their second year. Before this time it is less than the maximum because

so much has still to be added by the further growth of the young fish. After the second year it decreases again as the older fish are gradually removed, either by angling or by natural deaths. *If anglers are to be able to take as much as possible of the weight of trout the stream can produce they must be able to take the fish of each year-class when their total weight is at its maximum. If the size-limit is so high that it prevents fish from being taken until their year-class has passed its maximum weight, then, however thoroughly the water is fished, the angling catch can never be as great as it could have been if the capture of younger fish had been allowed.*

The way in which a size-limit which is too high reduces the total catch anglers can get is demonstrated in the following example, and is illustrated in Figs. 11A and 11B. The figures on which the example is based are those which we have already seen to apply in the Horokiwi (*i.e.*, in the years when fish are being removed by angling, 80 per cent die each year, and of these deaths one-third are due to angling). The weight-for-age figures used are those typical of the Lower Waters. In this example we start with a stream containing 100 trout at the beginning of their third year. We then compare the total yield anglers can get when the size-limit is such as to allow these fish to be taken immediately, with the yield that would be got if the size-limit protected the fish from angling until they entered their fourth year:

TAKEABLE IN THIRD YEAR

		Wastage.	*Anglers' Catch.*
Third year .	100 trout		
	80 die	53 to natural causes	27 to anglers.
			Average weight, 12 oz.
			Total weight, $20\frac{1}{4}$ lb.
Fourth year .	20 trout		
	16 die	11 to natural causes	5 to anglers.
			Average weight, 1 lb.
			Total weight, 5 lb.
Fifth year .	4 trout	2 to natural causes	1 to anglers.
	3 die		Average weight, $1\frac{1}{2}$ lb.
			Total weight, $1\frac{1}{2}$ lb.
	1 trout		
	Total yield to anglers .	.	33 trout, $26\frac{3}{4}$ lb.

Under these conditions about three-quarters of the weight of the anglers' catch is made up of third-year fish, but a number of larger fish are also caught. If the size-limit is raised to protect third-year fish, the number of larger fish caught is almost doubled, but this does not compensate fully for the loss of the smaller fish from the catch, which therefore decreases.

TAKEABLE IN FOURTH YEAR			
Third year .	100 trout		
	65 die	(= 53 as before + 12 of those previously caught by anglers)	
Fourth year .	35 trout		
	28 die	19 to natural causes	9 to anglers. Average weight, 1 lb. Total weight, 9 lb.
Fifth year .	7 trout		
	6 die	4 to natural causes	2 to anglers. Average weight, 1½ lb. Total weight, 3 lb.
	1 trout		
	Total yield to anglers . .		11 trout, 12 lb.

This example shows that, under conditions like those in the Horokiwi, raising the size-limit sufficiently to increase by one year the age at which trout can first be legally caught would greatly reduce the anglers' catch. The number of fish caught is only a third of that with the lower limit, and the total weight is less than half. On a more heavily fished stream the difference would be even greater. In the extreme case fishing might conceivably be so heavy that all fish were caught as they reached legal size and none over this size died naturally. In such circumstances the total catch with the lower limit would be 100 fish, weighing 75 lb., while with the higher limit it would be only 20 fish, weighing 20 lb.

To give the best possible results the size-limit in any trout stream should therefore be fixed at a length which allows as many fish as possible to be caught at the age at which the total weight of their year-class is at a maximum, provided that sufficient numbers of spawners are left to continue the stock. In the Horokiwi we have seen that the greatest weight occurs during the second year, and that nearly all the trout spawn at the end of this year. To allow an adequate number of fish to spawn the size-limit should therefore prevent many fish being taken before the end of their second year. To keep wastage due to natural deaths to a minimum, all the trout should be takeable in their third season. The ideal size-limit under these conditions would be a length which the average trout reaches near the end of its second year.

The present size-limit of 11 in. closely fulfils this condition on the Lower Waters of the Horokiwi, and it could hardly be improved upon in this respect.

A very different state of affairs is found in the Upper Waters. Here the slower growth prevents all but a few fish from reaching the size limit until

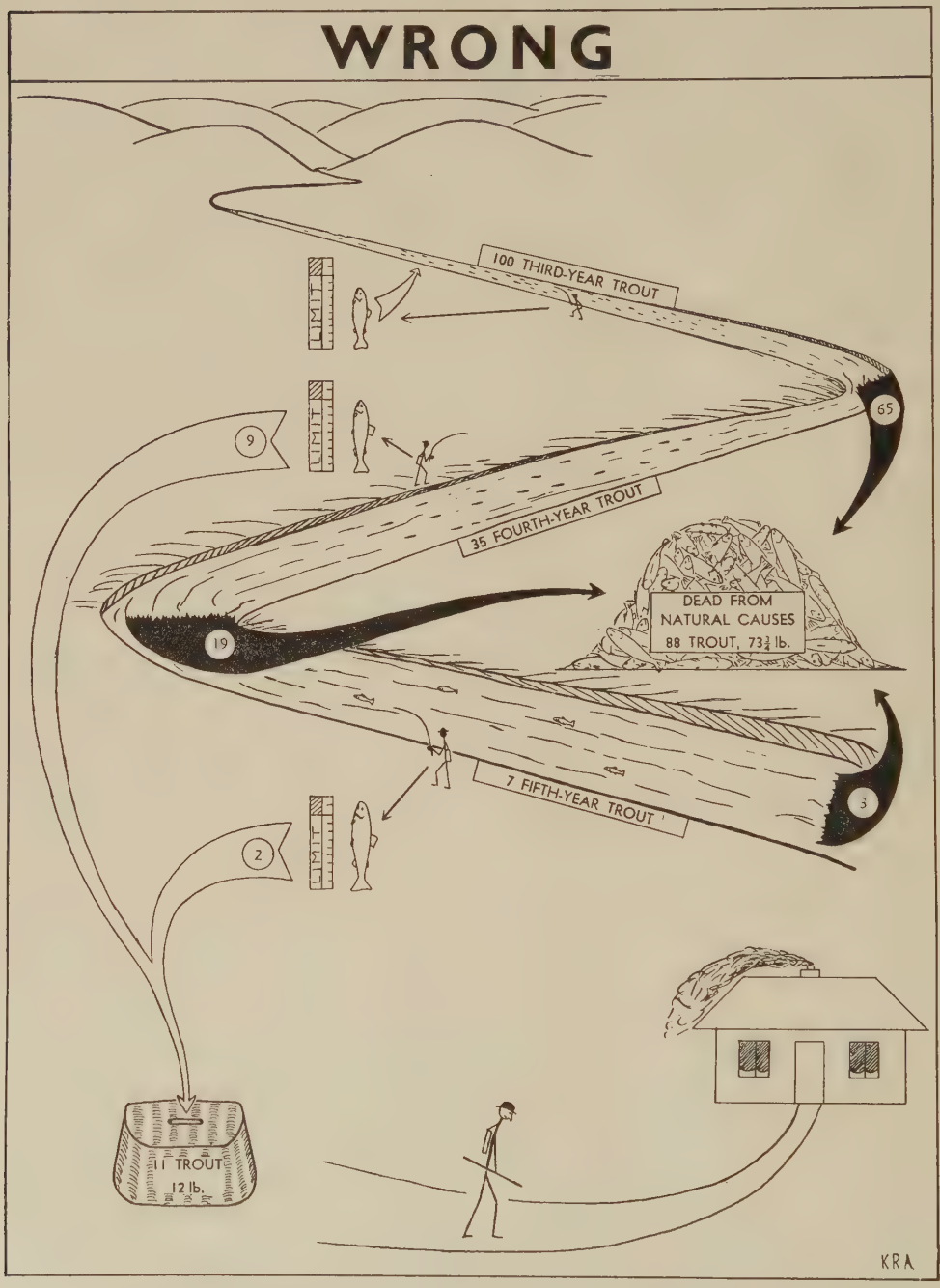


Fig. 11A. A size-limit which is too high simply leads to a waste of fish. In the trout stock shown in this and the next figure the best size-limit would be one which allowed the trout to be taken in their third year. If, as in this figure, the limit is too high, so that they cannot be legally taken until their fourth year, the angler's catch is small, and a large number die from natural causes.

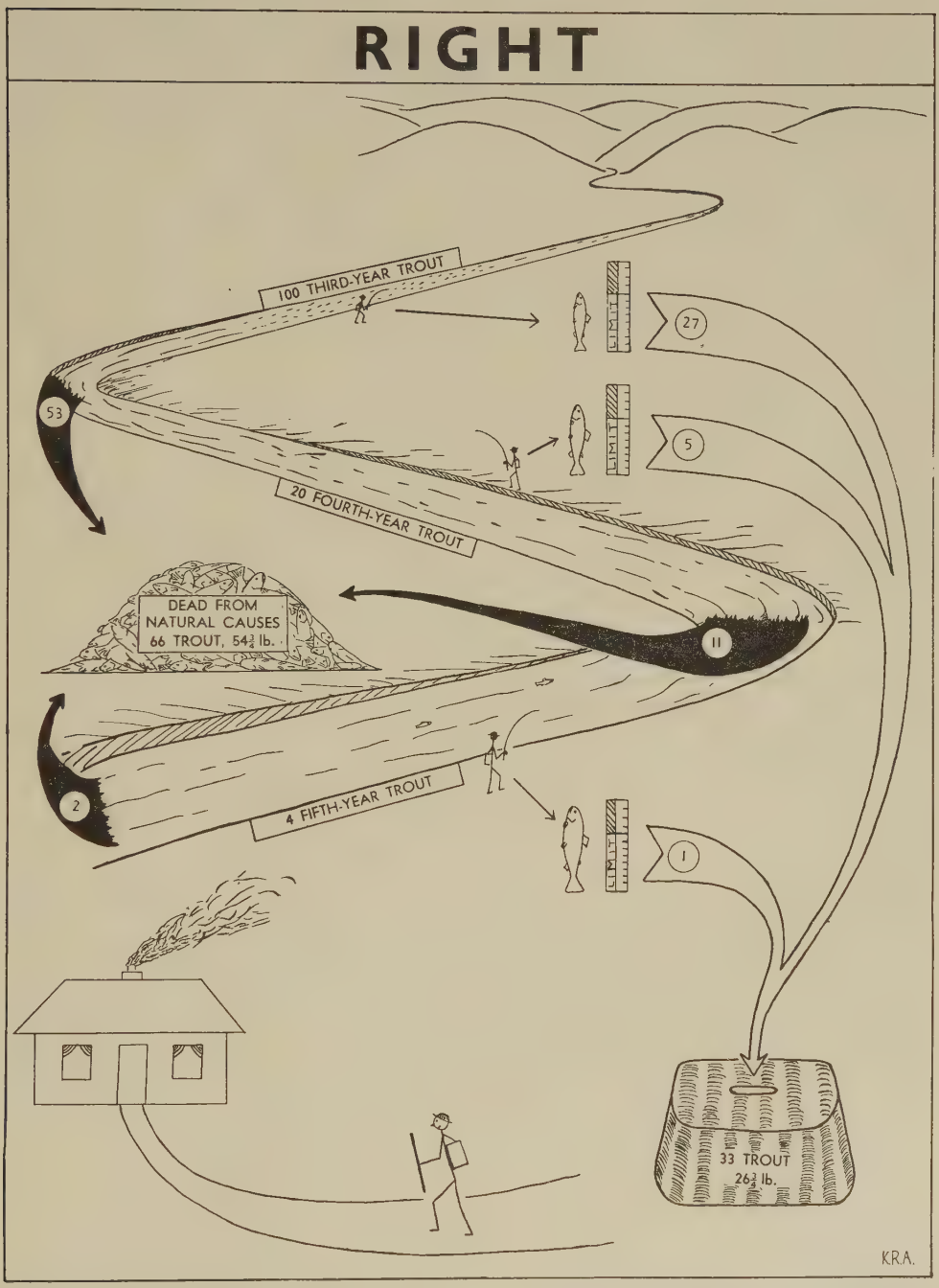


Fig. 11B. The same trout stock with the correct size-limit. From the same original number of fish (100 in their third year) the anglers are able to take three times as many, weighing more than twice as much as when the limit was too high. The amount wasted by natural deaths is correspondingly less.

the beginning of their fourth year. As a result they are unnecessarily protected from angling for two spawning seasons instead of one. They are also, unnecessarily, protected for more than a year after the weight of the stock has reached its maximum, and in that year three-quarters of the stock is lost by natural causes. The 11 in. limit therefore leads here to a needless waste of trout. It may perhaps also allow too prolific spawning, and this in turn produces excessive competition for food and so reduces the growth rate still further. There can be no doubt that in these waters the 11 in. size-limit is quite unsuitable. A limit of $9\frac{1}{2}$ in. would have about the same effect here as the 11 in. limit has on the Lower Waters. It would greatly increase the yield obtainable by anglers, and it would, if anything, benefit rather than harm the stock.

While on biological grounds there is evident need for different limits on these two parts of the stream, such a provision would produce serious administrative complications. The practical enforcement of different limits on such closely adjacent waters might be difficult. The situation would also provide a ready-made excuse for the few anglers who might wish to take fish of less than 11 in. in the lower waters. More important, perhaps, is the difficulty which even well-intentioned anglers might have in understanding and observing such minor local variations. In such a situation two courses are possible; either to adopt the limit appropriate to the more popular and heavily fished water, or to adopt a compromise figure which will not depart too far from the biologically desirable value on any part of the stream. The present situation represents, by chance, the first alternative. The second alternative, a compromise size-limit, would lead to the taking of rather more second-year fish from the Lower Waters before they had spawned. The most obvious compromise, 10 in., would probably about double the number of second-year fish killed, and would reduce the number of spawners by about 10 per cent. The exact effect would probably vary from season to season, according to the rate at which the fish grew, and to the relative amounts of fishing done early and late in the season.

The choice between these two alternatives is therefore, in essence, either of maintaining the present conditions or of enabling anglers to take more fish from the Upper Waters at a possible risk of reducing the spawning stock in the Lower Waters. Present information suggests that this risk is very slight, but the factors involved require accurate measurement, and may vary greatly from season to season. The experimental application of such a change for a few years, and careful observation of the results, is probably the best and safest way of obtaining the maximum yield from a stream containing such diverse conditions.

THE BAG-LIMIT

The object of a bag-limit is to reduce the number of fish caught, and possibly to enable them to be rather more evenly distributed among anglers, regardless

of skill. The effectiveness of such a measure depends on the assumption that any fish which were saved because an angler had stopped fishing when he reached his limit would later be caught by another angler. In a very heavily fished stream this might happen, but such a condition is very rare in New Zealand. The Lower Waters of the Horokiwi seem to be as heavily fished as most New Zealand streams, but only about one-third of the takeable fish are killed by anglers, the rest die from natural causes. In such a stream two-thirds of the fish saved by the bag-limit would therefore be wasted and only one-third could be expected to appear in later bags. *The effect of the bag-limit here is therefore to cause the wastage of two-thirds of the fish which it initially saved.*

The actual effect produced will depend on the number of fish saved and hence upon the frequency with which anglers have to give up fishing because they have reached their limit. During this work records were obtained of 530 daily bags, including 1,030 fish. On only three of these days did the angler reach his limit. The number of fish saved by the bag-limit was therefore the number of extra fish which would have been caught on those three days. This is obviously very small compared with the number of fish actually killed, and therefore both the initial saving and the final wastage which the bag-limit produces are very small on the Horokiwi. It may be noted that the general survey of New Zealand angling which has been made in the last few years by means of the diary scheme has shown that in most waters limit bags are about as rare as they are on the Horokiwi. *The bag-limit, therefore, has generally no significant effect on angling catches or fish stocks.* There are a few exceptions in places where the bag-limit is unusually low and does restrict catches appreciably.

RANGING

It seems desirable in this general discussion of fishery management practice to refer to ranging. This is not actually an additional method. The function of a ranger is to put into effect the various practices discussed earlier—to liberate fish, to carry out or organize predator control, to enforce regulations, and so on. In a district with an efficient ranger, such methods as the controlling authorities adopt are operated effectively, but ranging is not, in itself, an additional technique of fisheries management.

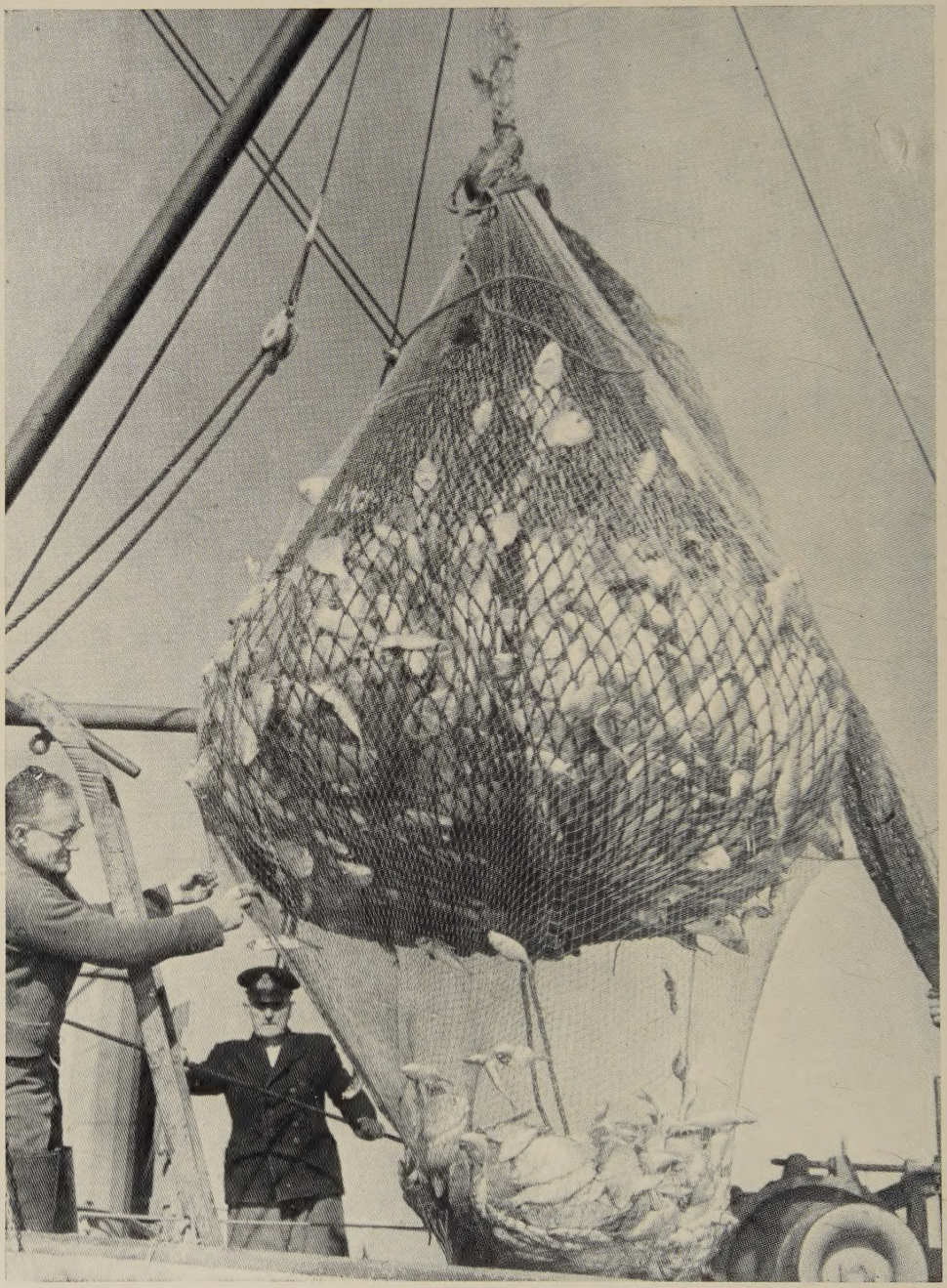
GENERAL APPLICATIONS

In the preceding sections of this chapter most of the prevalent methods of fisheries management in New Zealand have been discussed. In most cases the present work has made it possible to assess the value of these methods as they are,

or could be, applied on the Horokiwi. If this were the limit to which these results could be given practical application it might be difficult to justify the expenditure of so much time and effort on the study of one small trout stream. In practice we have seen that they have much wider applications. In some cases, such as the relations between liberations, the amounts of natural spawning, and the natural mortality rate, the figures are themselves applicable with only small change to many other trout waters. In other instances this detailed study has brought to light general principles which can be applied on other waters after very much less detailed local studies. The principles underlying the fixing of size-limits are an example of this. It has already proved possible to apply these on other streams after only a few days spent on intensive study of the particular factors, such as growth-rate and age at maturity, which are especially concerned.

It is therefore believed that, although the study described in this book was concentrated on a single small trout stream and was concerned to a considerable extent with theoretical concepts regarding trout populations, it has, for these very reasons, produced results which can be given valuable practical applications on many other trout waters.

R. E. OWEN, GOVERNMENT PRINTER, WELLINGTON



FRONTISPIECE. The cod-end and cover being taken aboard after a covered-net experiment. There are over 1,000 snapper in the cod-end, weighing three-quarters of a ton